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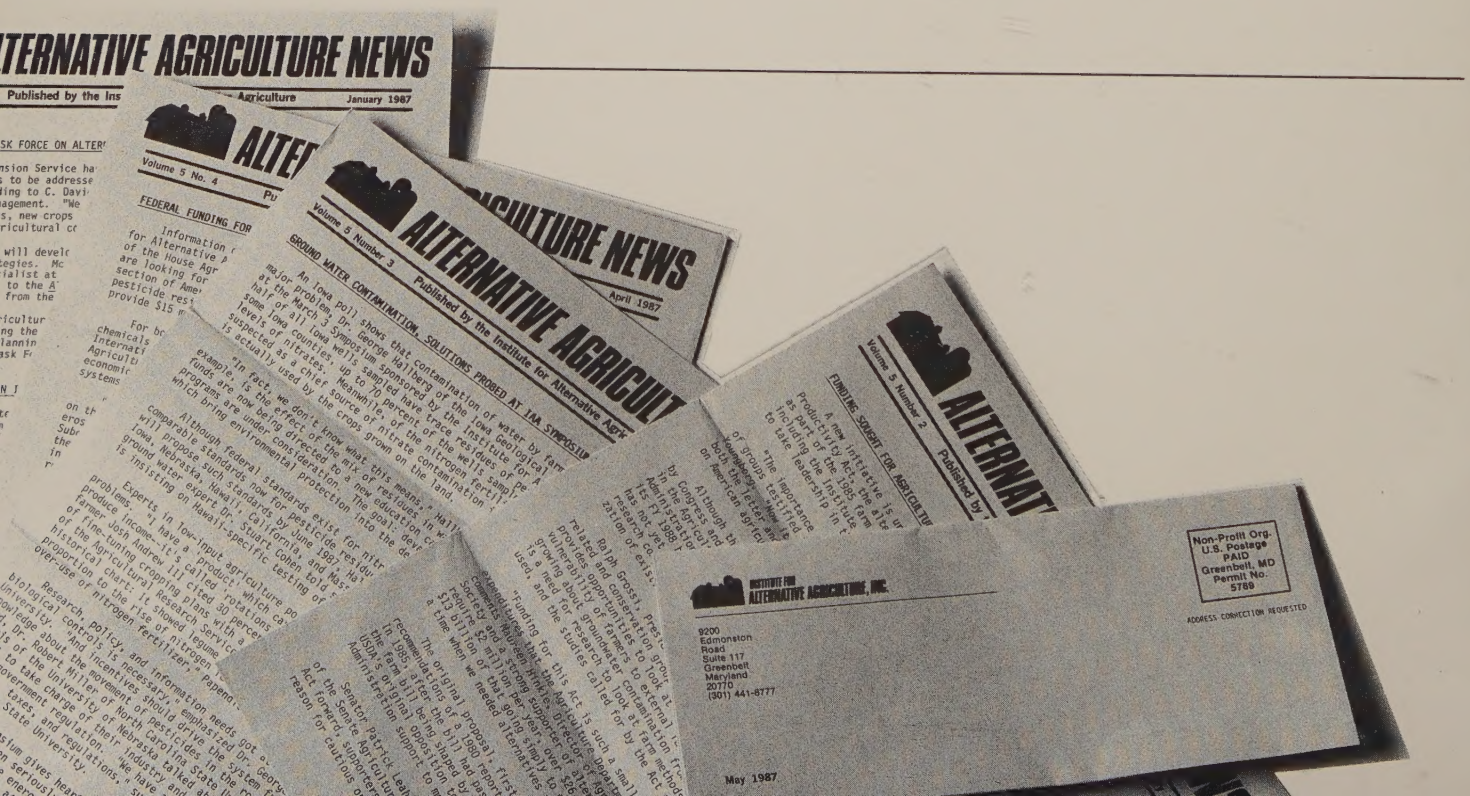
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Its programs include providing a national information clearinghouse, serving as a voice for sustainable agriculture in Washington, and developing and implementing research and educational outreach programs. It holds an annual scientific symposium and publishes a monthly newsletter.

The Institute is governed by a grass roots Board of Directors, which includes several commercial-scale organic farmers, and maintains a small professional staff. It is supported by memberships and donations and grants from foundations, corporations, and individuals.

Cover Photo

An intercrop of hairy and bigflower vetch (foreground) and a rye/hairy vetch intercrop (midground) grows on the Virginia Tech research farm near Blacksburg. Mixtures of cover crop species were used to provide plowdown green manure nitrogen for silage corn. Photo proided by Preston Sullivan, recent graduate of the Crop and Soil Environmental Sciences Department at Virginia Tech, now employed by ATTRA (Appropriate Technology Transfer for Rural Areas) in Fayetteville, AR.

Cover crop contributions to N supply and water conservation in corn production

Preston G. Sullivan, David J. Parrish, and John M. Luna

Abstract. *Winter annual legume cover crops can reduce nitrogen (N) fertilizer requirements and provide a water-conserving mulch to a subsequent crop. A two-year study was designed to test cover crops of rye (*Secale cereale *L.), hairy vetch (*Vicia villosa *Roth), and bigflower vetch (*Vicia grandiflora *Scopoli) for their ability to produce N and to conserve soil water for a succeeding corn (*Zea mays *L.) crop. We measured the cover crops' biomass, N yield, carbon (C) to N ratio, and influence on a subsequent corn crop grown under two tillage regimes (disk tillage or no-till). Nitrogen content in cover crop biomass at time of corn planting ranged from 37 to 187 kg/ha. Pure stands of hairy vetch and a mixture of hairy vetch plus bigflower vetch had generally higher N yields, and rye was lowest. Rye growing in association with hairy vetch had lower C:N ratios than rye growing alone. Legume C:N ratios remained generally unchanged from earlier (disked) to later (herbicide) kill dates, but total N and biomass typically increased in the last 2 to 3 weeks before corn planting. Soil water retention was affected by tillage in some cases; no-till was superior to disk incorporation in each case where there was a tillage effect. Cover crops with greater biomass resulted in greater soil water retention. Among cover crops, uptake of N by corn was greater from hairy vetch or hairy vetch plus bigflower vetch mixture. Biological immobilization of N appeared to be reducing N uptake by corn grown in rye residues. Corn in nonlegume plots fertilized with 140 or 210 kg N/ha took up more N than corn following legumes, but there was no corresponding yield increase. Corn biomass yields following the cover crops ranged from 8.6 to 18.0 Mg/ha with no additional fertilizer N. In the second year of the study, average corn yields following hairy vetch (15.3 Mg/ha) or hairy-bigflower vetch mixtures (16.4 Mg/ha) were not statistically different from corn yields produced by a 140 kg N/ha fertilizer rate (17.4 Mg/ha). These results suggest N from a legume cover crop can replace or substantially reduce fertilizer N requirements in corn production systems in the Appalachian region.*

Key words: cover crop, green manure, intercrop, mulch, water conservation, rye, hairy vetch, bigflower vetch

Introduction

Winter annual legume cover crops present an opportunity to substantially reduce fertilizer N requirements and to conserve soil moisture for corn production. In many cases, corn grown following legume cover crops has produced near maximum yields with minimal additions of N fertilizer (Decker et al., 1987; Frye et al., 1985; McVay et al., 1989). Using N uptake methods, Mitchell and Teel (1977) estimated that corn recovered 38 percent of the N in a cover crop residue. Huntington et al. (1985) reported 29 percent recovery of cover crop N by corn under no-till conditions. Herbek et al. (1987) found fertilizer N replacement values of 50 and 73 kg N/ha for hairy vetch and bigflower vetch, respectively. Tyler et al. (1987) and Neely et al. (1987) reported fertilizer N equivalents for corn of 84 to 112 kg/ha from a killed vetch cover. A New Jersey study compared corn yields following rye (*Secale cereale* L.) plus 200 kg N/ha to those obtained with unfertilized hairy vetch (Tisdale et al., 1985). Though corn silage yields following vetch were slightly less than those following rye plus N, the vetch system gave a greater net return per ha and a lower production cost.

Tillage can affect the rate at which cover crop N is mineralized and becomes available to a following crop. Varco et al. (1989) reported 32 percent recovery of hairy vetch N by corn under conventional tillage and 20 percent with no-till. Wilson and Hargrove (1986) examined N release from residue of crimson clover (*Trifolium incarnatum* L.) 16 weeks after the cover crop was killed. They found 64 percent of the clover's N was released under no-till conditions and 69 percent under conventional tillage. One month after planting corn into hairy vetch, Utomo et al. (1985) found available soil N in conventionally tilled plots increased by 99 percent, while the increase was only 13 percent in no-till plots. Corn yields were greater with conventional tillage than with no-till, presumably because of greater N mineralization. Varco et al. (1989) noted that incorporating a hairy vetch residue resulted in greater N recovery by corn than when the vetch was killed and left on the surface.

Proper timing of cover crop kill with herbicides offers potential for synchronizing N release with corn's N demand. Huntington et al. (1985) reported a large release of legume N after time of silking when corn was grown in a no-till hairy vetch mulch. This timing of N release did not correspond well to the corn's N

Preston Sullivan is Technical Specialist, ATTRA, P.O. Box 3657, Fayetteville, AR 72702, and former graduate research assistant in Crop and Soil Environmental Sciences at Virginia Polytechnic Institute and State University. David Parrish and John Luna are faculty members in the Crop and Soil Environmental Sciences and Entomology Departments, respectively, VPI & SU, Blacksburg, VA 24061.

uptake pattern. Wagger (1989) reported faster N release from hairy vetch and crimson clover when they were killed 2 weeks before rather than at corn planting. Additional legume N did accumulate in the cover crop when cover crop kill and corn planting were delayed, but the delayed N release following the later kill offset the higher N content.

In addition to their biologically fixed N, killed cover crops can provide a water-conserving mulch. Moody et al. (1963) found that available soil water was 28 percent higher in July and 17 percent higher in August in corn plots mulched with wheat straw at 6.7 Mg/ha, compared to unmulched plots. Mulched plots yielded 2.6 Mg/ha more corn grain than did unmulched ones. Increased soil water was attributed to higher water infiltration and reduced runoff and evaporation. Blevins et al. (1971) found consistently higher soil water levels for corn grown in a herbicide killed, no-till, bluegrass (*Poa pratensis* L.) sod than for corn grown in conventionally plowed and disked plots. They concluded that decreased evaporation and increased water storage under the no-till mulch allowed the corn to survive a short-term drought without severe water stress.

In this study, we have investigated the N producing ability of two vetches grown alone, together, or with rye. We have also examined the cover crops' contribution to corn yield and N uptake when the corn was grown under two tillage regimes and soil water status under these various cover crop and tillage systems.

Materials and methods

Replicated small plot experiments were established near Blacksburg, Virginia (37 ° N, 80 ° W, and 600 m elevation), on a Hayter cobbly loam (fine, loamy, mixed mesic, Ultic Hapludalfs). This soil has a loamy surface texture and 2 to 7 percent slope and is well drained. The site had been in a pasture of tall fescue (*Festuca arundinacea* Schreb.) plus white clover (*Trifolium repens* L.) from 1984 to 1987 and in corn for at least 3 years before the pasture.

On 10 July 1987, the plot area was disked repeatedly with an offset disk to kill and incorporate the pasture plants. Foxtail millet (*Setaria italica* L. Beauvois) was planted on 16 July using a grain drill, at a seeding rate of 28 kg/ha. The millet crop was intended to extract and immobilize residual soil N in its biomass. Because of drought (no rain from 7 July to 6 September), the millet crop failed. The experimental area was treated with 4,500 kg dolomitic limestone/ha on 8 September 1987. The area was chisel plowed and disked, and a cover crop seedbed was produced by harrowing on 10 September 1987.

The experiment involved planting corn into killed cover crops with no added N or into winter fallow plots with various rates of N fertilizer. The five cover crop treatments were pure stands of rye, hairy vetch, and bigflower vetch and two mixtures of these species (Table 1).

A Northrup King short-growing rye variety ('SS2'), 'common' hairy vetch, and 'Woodford' bigflower vetch were used in the 1987-1988 season. 'Abruzzi' rye was used in 1988-89 because SS2 showed signs of freeze injury during the winter of 1987-88.

Cover crops were planted as pure stands or mixtures using a grain drill on 25 September 1987 and on 8 October 1988. Row width for cover crops was changed from 10 cm to 20 cm in the second year to keep the drill from clogging on corn stump/root masses when set for the narrower width. Seeds of the various mixtures were inoculated with appropriate *Rhizobium* strains. No N was applied to any of the cover crops.

On 30 March 1988, inspection of the vetches revealed that many plants, particularly those in the pure stands, were not uniformly nodulated. The vetch plants in some plots, particularly the rye-vetch mixtures, seemed to be adequately nodulated. We suspect that the inoculum used in Fall 1987 was of poor quality or that available soil N reduced nodulation. A different source of inoculum was used for all subsequent inoculations, and the legumes were planted into the same plots in Fall 1988. In the second year, no nodulation problems were apparent.

Fall planted cover crops were killed in the spring either by disk incorporation or by desiccation with paraquat. Disked plots were disked earlier (2 to 3 weeks prior to corn planting), whereas herbicide killed plots were sprayed immediately prior to corn planting. The two kill-date/tillage systems confound the experiment and are being considered as two separate systems at a farmer's disposal. Cover crops to be incorporated, as well as fallow plots, were disked on 27 April 1988 and 8 May 1989.

P and K fertilizer was applied for the corn crop according to Virginia soil test recommendations at 56 kg P_2O_5/ha and 56 kg K_2O/ha over the top of cover crops or fallow plots just prior to disking or herbicide killing in both years. Paraquat

Table 1. Treatments used in the 2 × 5 and 2 × 6 factorial arrangements, plus additional treatments.

Cover crop treatment	Cover crop seeding rate	Fertilizer N⁺	Tillage method (Disked or No-till)
	kg/ha		
2 × 5 Factorial Study			
Rye (R)	100	0	both
Hairy vetch (H)	28	0	both
Bigflower vetch (B)	28	0	both
Two vetch	19H + 9B	0	both
Rye-vetch	50R + 19H	0	both
Additional Treatments			
Fallow	—	0	disked
Fallow	—	70	disked
Fallow*	—	140	disked
Fallow	—	210	disked
Rye*	100	140	no-till

* These two treatments were added to the 2 × 5 factorial as "standard practice" controls (fallow plus disking = "conventional tillage", paraquat killed rye = "no-till") for corn yield and soil moisture comparisons in a 2 × 6 factorial study.

⁺ N added to the corn crop as NH_4NO_3.

at 0.42 kg a.i./ha, metolachlor at 1.68 kg a.i./ha, and cyanazine at 1.68 kg a.i./ha were tank mixed and applied to all plots (including those that had been disked) 17 May 1988 and 22 May 1989.

Pioneer 3233 corn was planted on 19 May 1988 and 22 May 1989 at a target population of 50,000 plants/ha. Stand counts were made on 5 June each year by counting plants occurring on 6 m of row. Skips were replanted immediately by hand to achieve the target population. Final plant populations (at harvest) ranged from 45,950 to 53,900 during 1988 and from 42,700 to 51,350 in 1989.

Fertilizer N at 0, 70, 140, or 210 kg N/ha was applied as granular NH_4NO_3 to the winter fallow plots. Half the total amount was spread on 28 May 1988 and on 24 May 1989. The second half of the N was broadcast when corn plants were approximately 50 cm tall.

Biomass produced by the cover crops was sampled from four 0.25 m^2 quadrats per plot by removing top growth to the soil surface. Cover crop plots that were to be disk incorporated were sampled 27 April 1988 and 8 May 1989. Cover crop biomass on herbicide killed plots was sampled just before desiccation and corn planting (13 to 17 May 1988 and 21 to 22 May 1989). Samples from the rye-vetch mixture were separated into the species components. No species separation of the two-vetch mixture was attempted. Cover crop biomass samples were weighed, dried at 60 C for 60 hours in forced air, and reweighed. Samples were ground to pass a 1 mm mesh screen and analyzed for both total N (Kjeldahl method:Bremner, 1965) and total C (Pragel method:Ma, 1979).

Nitrogen uptake by the corn crop was assessed from four corn plants randomly selected from each plot at approximately 3-week intervals. Nitrogen uptake sampling in 1988 occurred 23 June (35 days after corn planting), 18 July (60 days), 6 August (78 days), and 1 September (102 days). Samples for the 1989 corn season were taken 19 June (28 days following corn planting), 10 July (49 days), 1 August (70 days), 21 August (90 days), and 15 September (115 days). Plant samples were dried, ground, and analyzed for total N using the Kjeldahl digestion procedure (Bremner, 1965). Corn was harvested as for silage (35 to 42 percent dry matter) on 14 to 16 September 1988 and 13 to 15 September 1989 by cutting at ground level the central 12.2 m of the middle two rows of each plot. Subsamples were dried at 60 C for 60 hours with forced air, and yield data are reported as oven dry matter per hectare.

To assess differences in soil moisture, soil was sampled for water content during mild droughts at a growth stage when water demand was high (silking) on 6 August 1988 and 4 and 10 August 1989. Soil samples were taken to a depth of 30 cm, divided into two 15 cm sections, and analyzed for water percentage. Soil samples were placed in plastic bags, chilled immediately, and analyzed within 8 hours or frozen until analyzed. Soil water content was determined gravimetrically; samples were weighed when collected, dried in a convection oven at 105 C for 24 hours, and reweighed. Soil water was calculated on a dry weight basis as given by: [(wet weight - dry weight)/dry weight] x 100 percent.

Plots were 3.7 m wide (to accommodate four corn rows, 0.9 m apart) and 15 m long. The experiment was conducted for 2 years, with the same cover crop (or fallow) and tillage treatments imposed on the same plots each year. The overall design of the experiment was an unbalanced factorial with four randomized complete block replications (Table 1). Two tillage systems (earlier kill/disk and later kill/no-till) and five cover crop treatments were established in a balanced 2 x 5 factorial arrangement to study key cover crop parameters. Four N rates (0, 70, 140, and 210 kg N/ha) for corn following winter fallow (no cover crop) were randomized into each block to study corn's N response under disk tillage. The four N rates were analyzed separately to compare effects of several N fertilizer rates and cover crops on corn production. The treatment of 140 kg N/ha in disked fallow plots also served as a "standard conventional tillage practice" for comparison with a "standard no-till practice" of paraquat desiccated rye plus 140 kg N/ha. In the analysis of corn yields, these "standard practice" treatments (one for each tillage system) were added to the 2 x 5 factorial set of treatments, resulting in a 2 x 6 balanced factorial set. Statistical analyses consisted first of ANOVA (SAS, 1982) followed by mean separation using F protected LSD (Saville, 1990; Steel and Torrie, 1980). Due to treatment changes between the 2 years (different drill spacings and rye varieties), 2-year averages were not generated.

Results and discussion

Cover crop yields

Cover crop biomass and N production generally increased with a delay in date of killing, disked plots having been sampled and disked 20 (1988) and 14 days (1989) earlier than the paraquat killed, no-till plots. Significant main effects and interactions of cover crop and kill date (tillage) were seen in 1988 for biomass and N. In 1989, no interactions were observed, but biomass and N production again varied with cover crop species and kill date.

In 1988 under both tillage systems, the rye-vetch mixture yielded the most biomass at both kill dates, with rye second (Table 2). When killed earlier (disked), biomass yields of both pure stands of vetch and the two vetch mixture were similar, but less than those of rye alone or rye-vetch. When killed later with herbicide (no-till), rye-vetch and rye were again first and second in biomass production, and the two vetch mix was third. The pure vetch stands were similar and yielded less biomass than the other cover crops. When additional time (20 days) was allowed before killing them, all cover crops except the pure stand of hairy vetch accumulated more biomass. The lack of response by hairy vetch was likely due to poor nodulation and slow growth in several plots in 1988.

As it did with biomass, killing date affected N production of the various cover crops differently in 1988. The two vetch and the rye-vetch mixtures had superior N yield when killed later, but N yields in all other covers were unchanged between the earlier and the later kill date (Table 2). When the cover crops were killed earlier (disk incorporated), N yields among the two mixtures and pure hairy vetch were not significantly differ

Table 2. Effect of kill date on cover crop biomass and total N production, 1988.

Cover crop	Biomass			Total N		
	27 April	17 May	Kill date effect?	27 April	17 May	Kill date effect?
	Mg/ha			kg/ha		
Rye	6.2 b*	7.8 b	yes*	77 bc	57 c	no
Hairy vetch	3.4 c	3.8 d	no	101 ab	89 b	no
Bigflower vetch	2.4 c	3.5 d	yes	47 c	53 c	no
Two vetch	3.4 c	5.7 c	yes	113 ab	164 a	yes
Rye-vetch	8.3 a	10.9 a	yes	121 a	176 a	yes

* Means within a column followed by the same letter are not significantly different by F-protected LSD, alpha = 0.05.
+ Signifies whether the two means for a cover crop are significantly different, t-test using ANOVA root mean square error, alpha = 0.05.

Table 3. Effect of kill date on cover crop biomass and total N production, 1989.

Cover crop	Biomass			Total N		
	8 May	22 May	Kill date effect?	8 May	22 May	Kill date effect?
	Mg/ha			kg/ha		
Rye	4.3 ab*	5.2 b	yes+	42 d	37 b	no
Hairy vetch	3.8 abc	4.8 d	yes	143 a	187 a	yes
Bigflower vetch	3.1 c	4.1 b	yes	104 bc	148 a	yes
Two vetch	3.7 bc	4.3 b	no	128 ab	169 a	yes
Rye-vetch	4.9 a	6.7 a	yes	95 c	148 a	yes

* Means within a column followed by the same letter are not significantly different by F-protected LSD, alpha = 0.05.
+ Signifies whether the two means for a cover crop are significantly different, t-test using ANOVA root mean square error, alpha = 0.05.

Table 4. Effect of cover crop kill date on cover crop C:N ratios by year.

Cover crop component	1988			1989		
	27 April	17 May	Kill date effect?	8 May	22 May	Kill date effect?
	C:N			C:N		
Rye in pure stand	34.1 a*	58.0 a	yes+	43.9 a	60.5 a	yes
Rye from rye-vetch mixture	34.4 a	46.6 b	yes	44.3 a	46.7 b	no
Hairy vetch in pure stand	13.7 c	17.4 d	no	10.9 b	10.8 c	no
Hairy vetch from rye-vetch mixture	15.6 c	15.9 d	no	11.3 b	10.9 c	no
Bigflower vetch	19.3 b	26.5 c	yes	12.0 b	11.8 c	no
Two vetch mixture	12.7 c	14.2 d	no	11.6 b	10.7 c	no

* Means within a column followed by the same letter are not significantly different using F-protected LSD, alpha = 0.05.
+ Signifies whether the two means for a cover crop are significantly different, t-test using ANOVA root mean square error.

ent. There were no differences between total N in the hairy vetch and rye pure stands and the two vetch mixture.

During 1989, biomass yields increased significantly from the earlier to the later kill date for all cover crop treatments except the two vetch mixture (Table 3). The rye-vetch mixture had accrued more biomass than any other cover by the later kill date. When averaged across cover crops, biomass production went from 4.0 Mg/ha at the earlier kill date to 5.0 Mg/ha at the later. Average N content increased from 103 kg/ha to 138 kg/ha over the same period. Only pure rye failed to accumulate more N between the earlier and later kill dates. Similar results were recently reported by Wagger (1989).

We measured cover crop C:N ratios because of their effect on N mineralization rates and consequent N availability rates to the corn crop. When grown in a pure stand, the rye C:N ratio increased from the earlier to the later kill date (Table 4). The rye in pure stand and the rye portion of the rye-vetch mixture had similar C:N ratios at the earlier kill date, but the rye from the rye-vetch mixture had a significantly lower C:N ratio than rye in pure stand by the later kill date. Carbon content remained constant (40 to 43 percent) for rye and vetch at both sample dates, but N content of rye generally fell (data not shown), suggesting that N primarily influenced the C:N ratios seen in Table 4. There was a higher N percentage in the rye component when grown with vetch (0.9 percent) than in pure rye stands (0.7 percent) at the later kill date. Some N was apparently released by vetch, because we provided no additional N. An increased N concentration of grasses grown in association with legumes was shown recently with wheat and hairy vetch (Roberts et al., 1989) and many years ago with oats and field peas (Lyon and Bizzel, 1911). In 1989, when nodulation was uniform, all legumes had similar C:N ratios at both kill dates, and values for legumes were four to six times lower than for rye.

Nitrogen uptake by corn

Both tillage and cover crop affected the amount of N taken up by the corn.

Table 5. Effect of cover crop (averaged across two tillage methods) and tillage (averaged across five cover crops) on N recovered in corn plants at various times after planting, 1988.

Cover crop/Tillage	Days after planting			
	35	60	78	102
	kg N/ha			
Rye	4.8 c*	21 c	54 c	77 b
Hairy vetch	7.2 a	28 b	75 ab	133 a
Bigflower vetch	5.8 bc	22 bc	70 b	100 b
Two vetch	6.3 ab	34 a	90 a	137 a
Rye-vetch	5.6 bc	22 c	60 bc	81 b
Disked	7.8 a	29 a	79 a	109 a
No-till	4.1 b	22 b	59 b	102 a

* Means within a partial column followed by the same letter are not significantly different using F-protected LSD, alpha = 0.05. Cover crop and tillage effects were analyzed separately.

In 1988, corn in disked plots had accumulated more N than in no-till plots on all but the last sampling date (Table 5). Incorporation of cover crops typically hastens N mineralization; our findings support those of others (Sarrantonio and Scott, 1988; Varco et al., 1989) and extend them to the Appalachian region. When considering the various cover crops, we found the hairy vetch and two vetch treatments resulted in consistently higher N uptake into the corn's biomass. This can only partially be explained by the N present in the cover crop residues. The rye-vetch mixture contained as much N in its residues as the two vetch mixture (Table 2), but uptake by corn was quite different between the two treatments (Table 5). The differences undoubtedly reflect to some degree rates of N mineralization and the C:N ratio differences between the residues (Table 4).

In 1988, uptake of N by corn was not affected by N fertilizer increments applied to winter fallow plots. The means for 0 kg N/ha were consistently smaller, but they were not significantly different from those for 70, 140, or 210 kg N/ha at any sampling date (data not shown). This suggests the residual N, which we were unable to extract with the failed millet crop, was sufficient to sustain the corn's growth at the level imposed by the limiting factor. The lack of corn N uptake response to N fertilizer in 1988 raises interesting questions about the response to cover crops. It appears that N contributions *per se* were not driving the differences seen between cover crops (Table 5). Rather, the residues of some treatments, especially those containing rye, were depriving the corn of N that would have otherwise been available. This further confirms, and is an indirect way of deducing, the importance of residues' C:N ratios and the potential for biological immobilization of N.

In 1989, differences in corn's N uptake under various N fertilizer treatments were seen during the last half of the growing season (Figure 1). Nitrogen uptake by corn following cover crops in 1989 was unaffected by tillage, except on the first sample date (28 days), but N uptake for all treatments was very low at this time (< 7 kg/ha) (data not shown). Others (Utomo et al., 1985; Varco et al., 1989) have reported increased N recovery when legume cover crops were incorporated rather than killed and left as mulch, but those are often first-season studies. In our case, the 1989 data were taken after 2 years of cover cropping using the same treatments in the same plots. In such a situation, we might expect accumulation of soil N.

The seasonal trends of N uptake in the corn plants for cover crop treatments in 1989 corresponded well with the findings of Huntington et al. (1985), who noted a mid-season lag in N recovery by corn following hairy vetch. The same lag was seen in our 140 kgN/ha rate. Apparently the first half of the highest N rate (210 kg/ha) provided sufficient N until the other half was applied. Huntington et al. (1985) recommended applying N fertilizer at corn planting following cover crops to offset the N uptake lag. We suggest the supplemental N fertilizer be applied several weeks after planting to better compensate for the apparent pre-silking N deficit. Corn grown under the two higher N rates did take up more N than corn in cover crop plots but without a corresponding yield increase (Figure 1, Table 8), suggesting "luxury" N consumption. Because the Kjeldahl method used in this study only gives total N, the distribution of N among organic and inorganic forms within the plant was not determined. If the corn is ensiled and fed to ruminant animals,

Table 6. Effect of cover crop and tillage on soil moisture to 30 cm soil depth at several sample dates.

Cover crop	6 August 1988			4 August 1989			10 August 1989		
	Disked	No-till	Tillage effect?	Disked	No-till	Tillage effect?	Disked	No-till	Tillage effect?
	% water			% water			% water		
Rye	16.2 a*	16.0 ab	no+	18.0 a	18.3 ab	no	15.2 a	15.4 a	no
Hairy vetch	12.7 b	14.6 c	yes	17.1 ab	17.0 bc	no	12.9 ab	12.4 a	no
Bigflower vetch	11.4 bc	14.4 c	yes	15.0 ab	16.6 c	no	12.6 b	13.5 a	no
Two vetch	11.3 bc	14.8 c	yes	17.1 ab	17.5 bc	no	12.9 ab	12.5 a	no
Rye-vetch	15.0 a	16.5 a	yes	17.2 ab	19.5 a	yes	12.9 ab	14.5 a	no
Standard practice	11.0 c	15.3 bc	yes	13.7 b	16.8 c	yes	10.8 b	13.2 a	yes

* Means within a column (disked or no-till) followed by the same letter are not significantly different by F-protected LSD, alpha = 0.05.
+ Signifies whether the two means for a cover crop are significantly different, t-test using ANOVA root mean square error.

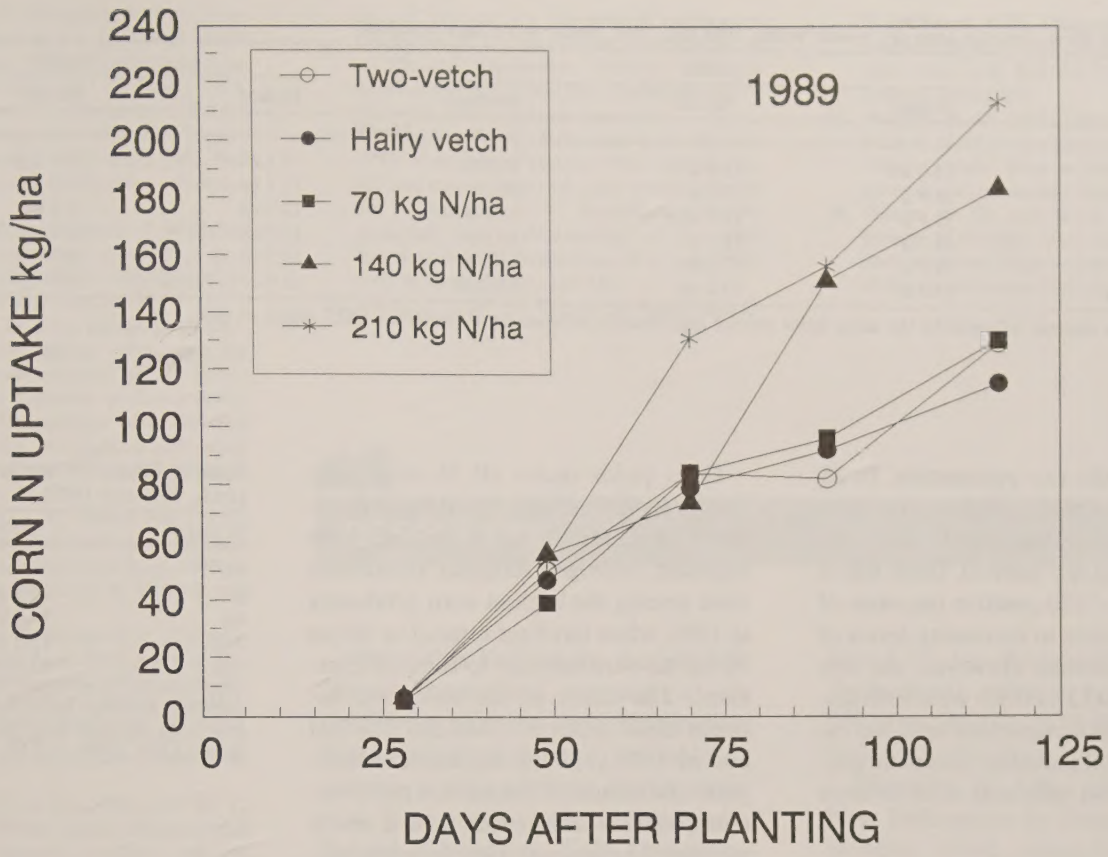

Figure 1. Nitrogen content of corn fertilized with various N rates or grown following vetch cover crops (averaged across two tillage methods) in 1989. The second half of each N rate was applied 70 days after planting.

higher N content may increase its feed value, since the ruminant microflora can convert some inorganic N to usable protein. If there is excess nitrate accumulation in the plant, however, which can result from excess soil nitrate concentrations or adverse environmental stresses, toxic silo gases can be released and nitrate poisoning of livestock can occur (Crawford and Kennedy, 1960).

Soil moisture

Abundant rainfall throughout the 1988 and 1989 corn growing seasons made it difficult to find a time of soil moisture deficit, even in the upper 30 cm. One moderately dry sample date was found in 1988 and two in 1989. No significant differences in soil moisture occurred with depth at any sample date; therefore means were averaged across both the 0 to 15 and the 15 to 30 cm sampling depths. Since the application of N fertilizer affected corn growth and consequently soil water extraction, the rye plus 140N and the fallow plus 140N standard practice treatments were included in the soil moisture analyses.

On the 6 August 1988 sample date, the plots with rye and rye-vetch that had been disk incorporated had more water in the upper soil layer than other cover crop treatments (Table 6). Under no-till, the rye-vetch mulch was similar to the rye mulch in retaining soil water but was superior to all other cover crop treatments. All cover crop treatments, except rye without N fertilizer, had more soil water in the upper 30 cm where a no-till mulch was in place. The high soil water content in the rye without N treatment may be misleading; plants in the rye and 0 N treatment were smaller and would not have extracted as much water as those receiving adequate N. Comparison between the desiccated rye plus 140N ("standard no-till practice") and the disked fallow plus the same fertilizer N ("standard conventional practice") are much more indicative of the soil conserving "mulch effect."

Sampling on 4 and 10 August 1989 revealed highly significant ($P < 0.001$) cover crop effects on soil moisture and no significant tillage by cover crop interactions (p-values of 0.28 and 0.15, respectively). On 4 August, no-till corn plots under the standard practice or the rye-vetch mixture had significantly greater soil water than disked plots. When cover treatments were averaged across tillage, no-till corn plots had significantly more soil water (17.6 percent) than disked plots (16.4 percent) ($p < .01$). At the dryer 10 August sample date, differences among cover/tillage treatments were small, except for the increased moisture content of no-till plots in the standard practice treatments.

To test the hypothesis that soil moisture was related to cover crop biomass,

Table 7. Effect of cover crops on corn dry matter yields, 1988 and 1989, under two tillage practices.

Cover crop	1988			1989		
	Disked	No-till	Average	Disked	No-till	Average
	Mg/ha					
Rye	14.0 a*	11.6 c	12.8 b	9.1 e	8.6 d	8.8 e
Hairy vetch	14.9 a	17.5 a	16.2 a	15.1 bc	15.5 ab	15.3 bc
Bigflower vetch	13.1 a	13.5 abc	13.3 b	13.9 cd	13.8 bc	13.9 c
Two vetch	14.7 a	18.0 a	16.4 a	16.5 ab	16.2 a	16.4 ab
Rye-vetch	14.5 a	12.6 bc	13.6 b	11.7 d	11.7 c	11.7 d
Standard practice	13.3 a	17.2 ab	15.2 ab	18.0 a	16.7 a	17.4 a

* Means within a column followed by the same letter are not significantly different by F-protected LSD, alpha = 0.05.

we regressed the two parameters. In 25 of the 27 linear regressions run on various depths, tillage, and sample date combinations (data not shown), there was a significant ($p < .05$) positive response of soil water content to increasing levels of cover crop biomass. However, the low values of R^2 (0.15 to 0.45) with both linear and quadratic regression analyses indicated that soil moisture cannot be predicted well from estimates of cover crop biomass.

Corn yields

To make these findings more immediately meaningful to growers, the two "standard practice" treatments were included with the cover crop treatments in the statistical analysis of corn yield. No significant differences ($P < 0.05$) in corn yields were discerned between tillage methods in 1988. The p-value for an interaction between cover crops and tillage was 0.07. No differences in corn yields following cover crop treatments were apparent when the cover crops were disk incorporated (Table 7). Among the no-till treatments, however, the hairy vetch and two vetch cover crop mixture produced significantly higher corn yields than the rye or rye-vetch mixtures, with yields similar to the standard practice, which included 140 kg N/ha.

For 1989, there were no tillage effects on corn yield and no interaction between tillage and cover crops. The vetch mixture cover crop treatments were equivalent to both standard practice treatments (Table 7). Yields following rye with no N added were decidedly inferior in 1989, suggesting that residual soil N was depleted.

Corn yields under all N rates were similar in 1988 (Table 8), additional evidence that residual soil N had not been depleted. Nitrogen fertilizer treatments were among the highest corn producers in 1989, when fertilizer rates at or above 70 kg/ha were superior to the 0 N treatment. The cause of the difference between mean yields in 1988 (13.7 Mg/ha) and in 1989 (15.9) is unknown. Allelopathic influences of the pasture plant residues, rainfall differences, and a much warmer than average 1988 growing season may have caused stress in the first year's corn crop.

Summary

The most cover crop N was produced by hairy vetch or a mixture of hairy vetch and bigflower vetch. When allowed to grow 2 to 3 weeks longer in the spring, cover crop N production increased. Rye growing in association with vetch had lower C:N ratios than pure rye, apparently deriving additional N from vetch. C:N ratios for legumes generally were unchanged when the cover crops were allowed additional growth time, suggesting that a later kill date would permit additional biomass without sacrificing residue/mulch quality (higher C:N ratios).

Uptake of N by corn was related to increased N production by cover crops and low C:N ratios. Using N fertilizer, greatest corn N uptake was observed with the two highest N rates (140 and 210 kg N/ha), but there was no corresponding yield increase over yields with N supplied by cover crops. Soil moisture in upper soil layers during a time of reduced rainfall was related to plant size and the presence of a surface mulch. Corn yields comparable to those obtained with N fertilizer application were achieved using legume cover crops without additional N fertilizer. Corn yields following the rye-vetch mixture were suppressed somewhat by N immobilization from the rye component and perhaps reduced N production by the vetch component. Addition of some N fertilizer to this treatment would be required to offset this effect.

Table 8. Effect of N fertilizer on corn dry matter yields, 1988 and 1989.

N rate	1988	1989
kg/ha	Mg/ha	
0	13.5 a*	10.6 b
70	14.6 a	16.4 a
140	13.3 a	18.0 a
210	13.6 a	18.6 a

* Means within a column followed by the same letter are not significantly different using F-protected LSD, alpha = 0.05.

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RESOURCES

Innovative Policies for Agricultural Research, abstracts presented at the conference held last November in Boston, Massachusetts, are available by sending a self-addressed flat envelope with $1.21 postage to: Molly Anderson, School of Nutrition, Tufts University, Medford, MA 02155.

Controlling Weeds with Fewer Chemicals, published by Rodale Institute, is available for $19.95 from The New Farm, 222 Main Street, Emmaus, PA 18098; (215) 967-5171.

Saving the Land that Feeds America: Conservation in the Nineties, the proceedings of a March, 1991, conference, is available for $15 plus $3.50 shipping from American Farmland Trust, 1920 N Street, NW, #400, Washington, DC 20036; (202) 659-5170.

Crop Residue Management for Conservation, a 49-page book based on the 1991 national conference of the same name, is available for $10 from the Soil and Water Conservation Society, 7515 NE Ankeny Road, Ankeny, IA 50021-9764; call 1-800-THE-SOIL.

Owning Farmland in the United States, a study and analysis of U.S. farm owners and operators, is available for $4 from the USDA's Economic Research Service (ERS-NASS), P.O. Box 1608, Rockville, MD 20849-1608; call 1-800-999-6779.

Sustainable Agriculture in the Southern Rockies: A Resource Directory of Producers and Practices, released by the Sustainable Mountain Agricultural Alliance, is available for $10 from SMALL, P.O. Box 1770, Telluride, CO 81435.

Diversity in U.S. Agriculture: A New Delineation by Farming Characteristics, which groups farm counties into 12 patterns of agricultural production, is available for $8 from the USDA's Economic Research Service (ERS-NASS), P.O. Box 1608, Rockville, MD 20849-1608.

Alfalfa Management Guide, a 41-page booklet published by the American Society of Agronomy, Crop and Soil Science Societies of America, University of Minnesota Extension Service, and University of Wisconsin-Extension, is $4.50 from ASA, CSSA, SSSA headquarters office, Attn: Book Order Department, 677 South Segoe Road, Madison, WI 53711-1086.

Agricultural Book Catalog, 88 pages, lists books and describes how to use the agAccess Research and Information Service. For a free copy, contact Jeffrey Harpain, agAccess, 603 Fourth Street, Davis, CA 95616; (916) 756-7177.

Setting Priorities: Research, Practice, and Policy for a More Sustainable Agriculture, the 1991 conference proceedings of the Leopold Center for Sustainable Agriculture, is available from the Center, 126 Soil Tilth Building, Iowa State University, Ames, IA 50011.

Farming Alternatives: A Guide to Evaluating the Feasibility of New Farm-Based Enterprises, ($6.50), and a companion video, "Farming Alternatives: Innovation on Northeast Farms," ($20), are available from the Northeast Regional Agricultural Engineering Service, 152 Riley-Robb Hall, Cooperative Extension, Ithaca, NY 14853; (607) 255-7654.

Livestock Health and Nutrition Alternatives: A Western States Conference, the report of a December, 1990, conference, is $8 from Alternative Energy Resources Organization, 44 North Last Chance Gulch, Helena, MT 59601; (406) 443-7272.

Alternative Farming Systems Information Center, at the National Agricultural Library, collects useful publications on alternative or sustainable agriculture and helps users to find them. To access AFSIC services, contact Jane Gates, AFSIC, Room 111, National Agricultural Library, 10301 Baltimore Boulevard, Beltsville, MD 20705-2351; (301) 344-3559.

Membership Directory of the Organic Foods Production Association of North America is available from Katherine DiMatteo, OFPANA, P.O. Box 1078, Greenfield, MA 01302; (413) 774-7511.

Specialty and Minor Crops Handbook, a looseleaf binder with sheets on 36 specialty crops, is $30 from UC Small Farm Center, University of California, Davis, CA 95616-8699.

BOOK NOTICES

Organic Farming. 1990. Nicolas Lampkin. Farming Press, Ipswich, Great Britain; distributed in North America by Diamond Farm Enterprises, Alexandria Bay, New York. xiii + 701 pp. Cloth.

This very detailed treatment of both the principles and practices of organic farming draws on contributions from over twenty British farmers and researchers. The discussion of practices is strongly oriented towards British growing conditions, economic institutions, production methods, and available equipment. However, U.S. readers interested in general principles of organic farming will find the book relevant, especially the first half.

Over-Fulfilled Expectations: A Life and an Era in Rural America. 1991. Harold F. Breimyer. Iowa State University Press, Ames, Iowa. xvi + 300 pp. $34.95, cloth.

This professional and personal autobiography by a prominent agricultural economist covers seven decades of agricultural history, from his boyhood on an Ohio farm in the 1920s to "nominal retirement" in the 1980s. Much of the book is devoted to changing farm policies, from the New Deal through the Reagan Administration. Also covered are Breimyer's years as a university teacher and extension economist.

Out of the Earth: Civilization and the Life of the Soil. 1991. Daniel J. Hillel. The Free Press Division of Macmillan, Inc., New York, New York. x + 321 pp. $22.50, cloth.

This book takes a broad view of soil, especially its treatment and mistreatment by people and its role in the rise and fall of civilizations. It covers many different regions from pre-Biblical times to the present. Special attention is given to problems such as erosion, deforestation, desertification, and salinization.

Beyond the Large Farm: Ethics and Research Goals for Agriculture. 1991. Paul B. Thompson and Bill A. Stout (eds.). Westview Press, Boulder, Colorado. 312 pp. $36.95, paper.

This collection of 12 papers is from a project whose purpose was "to establish dialogue between agricultural scientists, humanists, and social scientists who share an interest in the ethical and social aspects of agricultural research policy." It interprets this topic very broadly, covering both its national and international aspects from philosophical, ethical, and ecological viewpoints. Included are three lengthy bibliographic essays on family farm issues, environmental goals, and distributive justice.

Agriculture and Natural Resources: Planning for Educational Priorities for the Twenty-first Century. 1991. Wava G. Haney and Donald R. Field (eds.). Westview Press, Boulder, Colorado. xiii + 183 pp. $27.00, paper.

This edited volume is the result of the University of Wisconsin's efforts to develop a strategic plan. Its 11 chapters analyze a variety of human, institutional, and natural resource issues facing Wisconsin, such as land use, the international economy, agricultural marketing, and rural communities. It concludes with a discussion of ways by which the university can address these issues in the year 2020.

Chicken Little, Tomato Sauce & Agriculture: Who Will Produce Tomorrow's Food? 1991. By Joan Dye Gussow. The Bootstrap Press, New York, New York. 143 pp. $12.50, soft cover.

After analyzing the present North American predicament in food and agriculture, the author explores competing alternatives for the future. One is a small-scale, localized sustainable food system based on the proposition that humans cannot escape being a part of nature. Among the questions the author examines are: Must a choice be made? Do we need to produce more food?

Comparison of the effect of leaf rust on the grain yield of resistant, partially resistant, and susceptible spring wheat cultivars

R. P. Singh, T. S. Payne, P. Figueroa, and S. Valenzuela

Abstract. *Three hypersensitive resistant, six partially resistant (slow rusting), and one susceptible spring bread wheat (*Triticum aestivum *L.) cultivars were evaluated for grain yield, test weight, and kernel weight under artificially created epiphytotics of leaf rust disease (caused by* Puccinia recondita *f. sp.* tritici*) with and without fungicide protection for three years. Rusted plot yields were 4 percent lower compared to fungicide-protected plot yields for cultivars with hypersensitive resistance. In rusted plots, grain yield and kernel weight averaged 8 percent less for cultivars with partial resistance but varied from 2 to 20 percent less depending on cultivar. The susceptible check cultivar, Yecora 70, averaged 27 percent lower grain yield, 22 percent lower kernel weight, and 6 percent lower test weight in rusted plots. Slight reduction in test weight was also observed for each cultivar. Losses in grain yield could, therefore, be reduced to levels similar to those of hypersensitive resistant cultivars by the use of partial resistance. We discuss the sustainability of partial genetic resistance to leaf rust. Since partial resistance is expected to be durable, and since rust levels and effects on yield in farmers' fields are likely to be less than in this experimental plot study, partial resistance should give long-lasting resistance at a negligible cost in yield that is insufficient to justify the use of fungicides.*

Key words: CIMMYT, durable genetic resistance, partial resistance, Puccinia recondita tritici

Introduction

Leaf rust (*Puccinia recondita* Rob. ex Desm. f. sp. *tritici* Eriks. and E. Henn) is possibly the most important disease of wheat (*Triticum aestivum* L.) on a worldwide basis (Samborski, 1985). Genetic resistance to leaf rust has been used widely for the control of the disease. Usually a single major gene or combination of major genes were used. To date, 37 leaf rust resistance (*Lr*) genes have been cataloged (McIntosh, 1988). With few exceptions, these race-specific genes, when deployed individually or in combinations, resulted in the evolution of races with virulence for such genes or gene combinations. Therefore, resistance was not durable, that is, it resulted in cultivar susceptibility, because of selection pressures exerted by the resistant cultivar on the pathogen population in favor of an alternative virulence structure. Use of such genes in providing disease resistance to wheat cultivars often leads to serious epiphytotics with socioeconomic consequences (Saari and Prescott, 1985). Biotrophic fungi, such as the leaf rust pathogen, are particularly prone to rapid breakdown of cultivar resistance (Dyck and Kerber, 1985).

Stable yields through durable resistance to biotic stresses and tolerance to abiotic stresses is the main objective of the CIMMYT bread wheat breeding program. Durability of disease resistance can be achieved by combining additive resistance genes against the pathogen population or by interfering with the apparent rate of disease development. Multiline cultivars and varietal mixtures also come under this category. Incomplete or partial resistance, or slow rusting, could be based on minor genes or genes with small additive effects. It is considered to be more durable than resistance based on single, major, hypersensitive, or race-specific genes (Parlevliet, 1988), although the exact reasons for this are not clear.

Partial resistance to leaf rust (slow rusting) has been reported in several wheat cultivars (Kuhn et al., 1978; Shaner and Finney, 1980; Bjarko and Line, 1988a; Broers, 1989; Singh et al., 1991). Such resistance is characterized by suppressed disease development despite the ultimate expression of a high, "susceptible," infection type (Parlevliet, 1975, 1979, 1988). Thus disease development may occur, but its effect on grain yield will be slight. The rate of disease development is delayed as a result of longer latency period (the time between infection and sporulation), decreased receptivity (uredia per unit area), smaller uredia, or reduced sporulation (Ohm and Shaner, 1976; Parlevliet, 1979, 1988). Partial resistance to leaf rust in wheat is controlled by relatively few genes (Kuhn et al., 1980; Bjarko and Line, 1988b; R. P. Singh, unpublished), which means that it could be achieved through the accumulation of few such genes without going through complex breeding methods.

The test for durable resistance is time. The bread wheat cultivars "Thatcher,"

R. P. Singh is Geneticist/Pathologist, International Maize and Wheat Improvement Center (CIMMYT), Lisboa 27, Apdo. Postal 6-641, 06600 Mexico D.F., Mexico. T. S. Payne is Winter Wheat Breeder, CIMMYT, P. K. 39 Emek, Ankara 06511, Turkey. P. Figueroa and S. Valenzuela are Pathologists, Centro de Investigaciones Forestales y Agropecuarias, Cd. Obregon, Sonora, Mexico.

"Lee," and "Knox" have remained slow rusting for 55, 30, and 20 years, respectively (Wilcoxson, 1981; Ohm and Shaner, 1976). Wheat varieties common before 1930 in the Netherlands exhibited partial resistance to yellow rust (Dijk et al., 1988). West European barley cultivars in general possess partial resistance to barley leaf rust (Habgood and Clifford, 1981). "Red Rustproof" oats has exhibited slow rusting to crown rust for over 100 years (Luke et al., 1972). Partial resistance has long been observed and used by potato breeders against late blight (Niederhauser et al., 1954; Thurston, 1971).

Use of single gene resistances requires selection of resistant plant segregants from a population. Because partially resistant plants will support disease development, selection of this kind of resistance requires identification of "slow" versus "fast" rusting plants. Area under the leaf rust progress curve (AULRPC) is an effective measure of disease development on cereals (Buchenau, 1975). Partially resistant genotypes are characterized by slow disease progress, of which examples are shown in Figure 1 for the cultivars Bacanora 88 and Genaro 81, while fast-rusting genotypes exhibit faster disease increase (Figure 1, Yecora 70).

The objectives of this study were to assess the effect of leaf rust infection on grain yield in spring wheat germplasm possessing partial resistance to leaf rust under a heavy inoculum load. This study was done at Cd. Obregon, Sonora, Mexico, where leaf rust is a major disease of wheat but where resistant cultivars serve as the primary means of disease control.

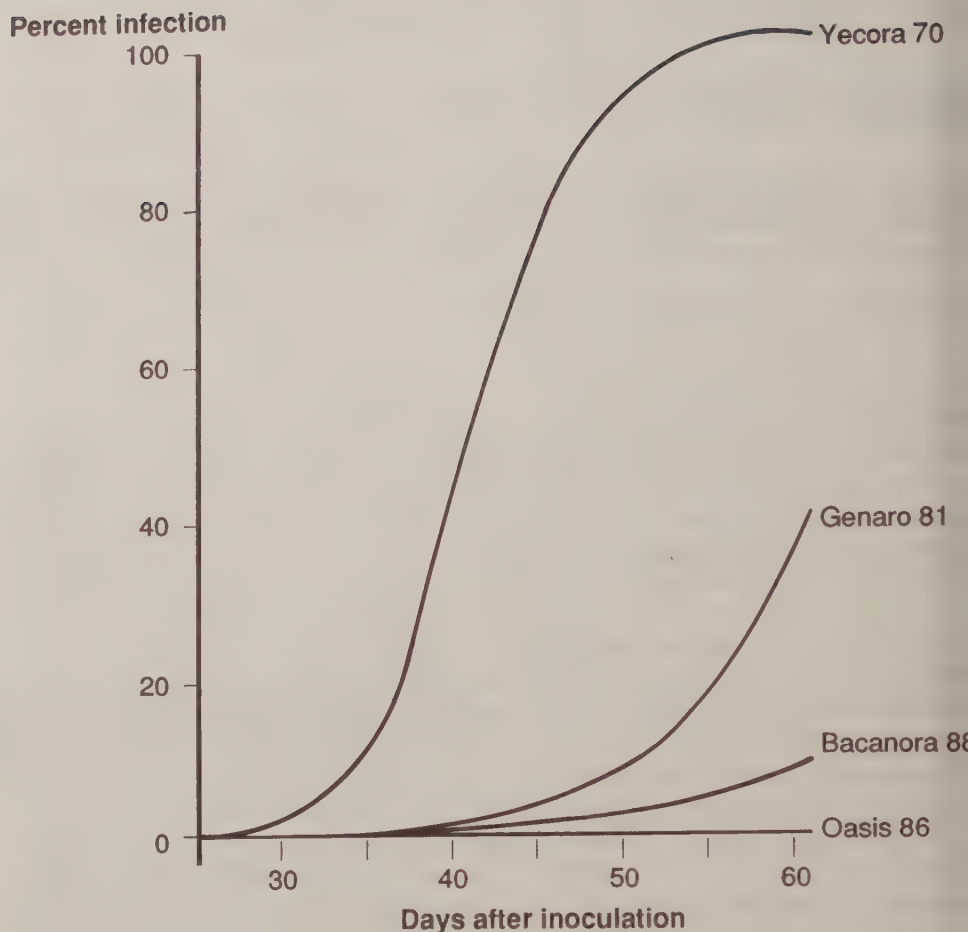

Figure 1. Leaf rust progress curves of the partially resistant spring wheat cultivars Bacanora 88 and Genaro 81, the completely resistant cultivar Oasis 86, and the susceptible cultivar Yecora 70 (Cd. Obregon, Mexico 1989-90).

Materials and methods

The ten spring wheat cultivars used in this study are listed in Table 1. Represented is germplasm developed by CIMMYT and released in Mexico and elsewhere (Villareal and Rajaram, 1988). "Oasis 86" is highly resistant to leaf rust due to a major gene *Lr19*. "Yecora 70" is the susceptible check. "Ciano 79" and "Papago 86" exhibit hypersensitive, resistant reaction to leaf rust, while the other six cultivars exhibit partial resistance to leaf rust. Hypersensitive resistance is characterized by macroscopic lesions at the infection sites. The early death of the host cells at these sites prevents the further growth of the fungal organism (Dyck and Kerber, 1985).

Two Mexican races of *P. r. tritici*, TCB/TD and TBD/TM (Singh, 1991), were used to create field epiphytotics. When inoculated with one or the other of these races, the partially resistant wheat lines displayed highly susceptible seedling infection types (based on the "0 to 4" infection-type scale described by Stakman et al., 1962; Table 1), indicating that none of the known, major, leaf rust resistance genes are functional in these genotypes against the respective races. Two races were used because some of the wheat genotypes listed in Table 1 possess known, major, leaf rust resistance genes, for which either race TBD/TM or TCB/TD is avirulent.

The ten wheat genotypes were planted in the field at Ciudad Obregon, Sonora, Mexico, during the 1986-87, 1987-88, and 1989-90 crop cycles in a split-plot arrangement of a randomized complete block design with three replicates. The two main plot treatments were exposed to an artificially induced leaf rust epiphytotic and were respectively designated rusted and protected. During 1986, each subplot (cultivar) consisted of eight rows, each 9 m in length, the central six of which were 20 cm apart with two rows 25 cm from the central rows that they bordered. During 1987 and 1989, each subplot consisted of four pairs of double rows seeded 15 cm apart with 75 cm between pairs. The length

Table 1. Wheat cultivars with their respective seedling and adult plant reactions and types of adult plant resistance when tested with *P. recondita tritici* races TCB/TD or TBD/TM.

Cultivar Cross and selection history[1]	Leaf Rust Reaction[2] Seedling	 Adult plant	Type of Resistance
Oasis 86 Agatha/3*Yecora 70 CMH77A 485-8B-5Y-1B-0B	0;	0;	Hypersensitive
Ciano 79 By/Maya/4/Bb//HD832.5.5/On/3/Cno/Pj (=Buckbuck) CM31678-R-4Y-2M-21Y/0M	1	1+	Hypersensitive
Papago 86 Buc/Pavon CM52359-2M-2Y-1Y-2M-1Y-0M	1	1+	Hypersensitive
Bacanora 88 Jup/Bjy//Ures (=Kauz) CM67458-Y4-1M-3Y-1M-5Y-0B	3+[a]	3	Partial
Opata 85 Bjy/Jup CM40038-6M-4Y-2M-1Y-2M-1Y-0B	3+[b]	3	Partial
Galvez 87 Bb/G11//Carp/3/Pavon (=Junco) CM33483-C-7M-1Y-0M-5B-0Y	3+[b]	3	Partial
Genaro 81 Kvz/Buho//Kal/Bb (=Veery #3) CM33037-F-12M-1Y-6M-0Y	3+[a]	3+	Partial
Pavon 76 Vcm//Cno/7C/3/Kal/Bb CM8399-D-4M/3Y-1M-1Y/1M-0Y	3+[b]	3	Partial
Seri 82 Kvz/Buho//Kal/Bb (Veery #5) CM33027-F-15M-500Y-0M-87B-0Y	3+[a]	3+	Partial
Yecora 70 Bluebird #2 II23584-26Y-2M-1Y-0M	4[a,b]	4	Susceptible Check

[1] Refer to Villareal and Rajaram (1988) for abbreviation and selection pedigree descriptions.
[2] Leaf rust reaction scale (Stakman et al., 1962) 0 to 4, where 0; = small, chlorotic flecks, 1 = small uredia surrounded by necrosis, 3 and 4 = susceptible reactions. The susceptible reactions 3 and 4 are distinguished by relative uredial size, where 4 is larger than 3, observed visually.
[a] Reaction to race TCB/TD.
[b] Reaction to race TBD/TM. Refer to Singh (1991) for race nomenclature and avirulence/virulence descriptions.

of the rows were 9 m in 1987 and 8 m in 1989. In each year, two planting dates were sown; 26 November and 31 December 1986, 1 and 22 December 1987, and 23 November and 13 December 1989. Prior to seeding, fertilizer was applied at the rate of 120 kg N/ha and 46 kg P/ha. The seeding rate was 100 kg/ha. All trials received five irrigations at 30-day intervals with a total of approximately 600 mm applied.

Each main plot was composed of 10 contiguous subplots (cultivars), with leaf-rust-susceptible "spreader" rows planted across the subplot ends. The spreader was composed of a mixture of highly susceptible spring wheat cultivars, including "Morocco." A leaf rust epiphytotic was created by inoculating the spreader plants at the beginning of culm elongation (Zadoks 3.1; Zadoks et al., 1974) with an equal mixture of *P. r. tritici* races TCB/TD and TBD/TM. Beginning with the first appearance of symptoms of infection on the susceptible cultivar Yecora 70, genotypes were rated for disease severity and reaction following the "Modified Cobb" scale (Peterson et al., 1948) at approximately 10-day intervals for a total of four recordings. The area under the leaf rust progress curve (AULRPC) was calculated from these disease observations using a computer program developed at CIMMYT, and the apparent rate of disease development was calculated according to Vanderplank (1963):

$$r = \frac{1}{t_2 - t_1}\left(\ln\frac{x_2}{1-x_2} - \ln\frac{x_1}{1-x_1}\right)$$

where t_1 and t_2 are the dates at which disease measurements are made, and x_1 and x_2 are the amounts of disease recorded on the respective dates.

Also beginning with the appearance of the first symptoms of infection on the highly susceptible Yecora 70, fungicide application was performed on the protected main plots. In 1986 and 1987, three applications of Bayleton 25 percent wettable powder (Triadimefon; Bayer AG, Germany), at two-week intervals, was applied at a rate of 0.5 kg/ha. In 1989, one application of Folicur (Tebuconazole; Bayer AG, Germany) was applied at a rate of 0.5 l/ha.

After trimming the border end 50 cm of the six central rows of each subplot in the 1986 experiment, and the two center row pairs of each subplot in the 1987 and 1989 experiments, subplots were machine harvested, with an effective harvested area of 10 m^2 in 1986, 14.4 m^2 in 1987, and 12.6 m^2 in 1989. Grain yield (g/m^2), test weight (kg/hl), and thousand kernel weight (g) were measured. Statistical analysis was performed using MSTAT-C (1988). Complex F-test degrees of freedom for Errors b, c, and e (Table 2) were calculated as described by Satterthwaite (1946).

Results and discussion

Epidemiological data for the ten spring wheat cultivars are presented in Table 2. Average values for AULRPC ranged from 0 (Oasis 86) to 2063 units (Yecora 70). The cultivars are listed in Tables 1, 2, and 4 in ascending order of AULRPC. Cultivars identified as exhibiting partial resistance to the leaf rust races were not easily distinguished from those exhibiting hypersensitive reactions, based only on AULRPC, but were merely represented as a continuum of AULRPC values. Information on the genetic basis of resistance and performance over years and locations form the basis for classifying a cultivar as partially resistant. The rate of disease development, as described by Vanderplank (1963), is another measure to characterize cultivar response to the disease; highly significant correlation (r=0.84; Table 5) was observed between the rate of disease development and the AULRPC. The values of the rate of disease development, pre-

Table 2. Area under the leaf rust progress curve (AULRPC), rate of disease increase, and final leaf rust response rating for ten spring wheat cultivars planted at two planting dates during three years.

		First planting date				Second planting date			
Cultivar	Year	AULRPC	Rate value	Rate % of Yecora	Final Leaf Rust rating	AULRPC	Rate value	Rate % of Yecora	Final Leaf Rust rating
Oasis 86	1986–87	0	0.000	0.0	0	0	0.000	0.0	0
	1987–88	0	0.000	0.0	0	0	0.000	0.0	0
	1989–90	0	0.000	0.0	0	0	0.000	0.0	0
	Mean	0	0.000	0.0		0	0.000	0.0	
Ciano 79	1986–87	18	0.008	3.8	5MR	41	0.048	24.5	30R-MR
	1987–88	70	0.023	11.4	10MR	14	0.000	0.0	2MR
	1989–90	7	0.034	9.3	5MR-MS	6	0.009	3.7	2MR-MS
	Mean	32	0.022	8.2		20	0.019	9.4	
Papago 86	1986–87	27	0.013	6.2	5MR-MS	110	0.074	37.8	50MR
	1987–88	283	0.063	31.8	20MR-MS	35	0.006	3.4	5MR
	1989-90	22	0.057	16.3	5MR-MS	6	0.019	7.4	2MR-MS
	Mean	111	0.044	18.1		50	0.033	16.2	
Bacanora 88	1986–87	66	0.028	13.2	5MS	85	0.042	21.4	10MS
	1987–88	203	0.053	26.6	15MS	30	0.001	0.4	5MS
	1989–90	74	0.061	17.5	10MS	19	0.028	11.0	2S
	Mean	114	0.047	19.1		45	0.024	10.9	
Opata 85	1986–87	48	0.035	16.8	10MS	251	0.072	36.6	30MS
	1987–88	308	0.064	32.4	20MS	59	0.006	3.4	5MS
	1989–90	31	0.034	9.8	5MS	19	0.047	18.6	5MS
	Mean	129	0.044	19.7		110	0.042	19.5	
Galvez 87	1986–87	100	0.028	13.6	10MS	90	0.030	15.3	10MS
	1987–88	312	0.063	31.8	20MS	135	0.036	19.5	10MS
	1989–90	32	0.036	10.4	10MS	27	0.017	6.7	5MS
	Mean	148	0.042	18.6		84	0.028	13.8	
Genaro 81	1986–87	179	0.072	34.5	20MS-S	295	0.087	44.2	35MS-S
	1987–88	620	0.090	45.2	40S	103	0.025	13.5	5MS-S
	1989–90	322	0.145	41.5	10MS-S	70	0.084	33.1	15MS-S
	Mean	374	0.102	40.4		156	0.065	30.3	
Pavon 76	1986–87	313	0.072	34.5	30MS-S	80	0.045	22.9	10MS
	1987–88	642	0.092	46.2	40MS-S	107	0.040	21.6	10MS
	1989–90	319	0.165	47.2	60MS-S	43	0.055	21.5	10MS-S
	Mean	425	0.110	42.6		77	0.047	22.0	
Seri 82	1986–87	340	0.100	47.9	40MS-S	380	0.106	54.1	50S
	1987–88	1337	0.139	69.7	80S	346	0.061	33.0	20MS-S
	1989–90	608	0.162	46.4	70S	180	0.134	52.8	40S
	Mean	762	0.134	54.7		302	0.100	46.6	
Yecora 70	1986–87	2055	0.209	100.0	100S	2363	0.196	100.0	100S
	1987–88	2332	0.199	100.0	100S	1676	0.185	100.0	100S
	1989–90	1802	0.350	100.0	100S	1235	0.254	100.0	100S
	Mean	2063	0.253	100.0		1758	0.212	100.0	

sented as percentage of the rate for Yecora 70 (Table 2), ranged from 0 for Oasis 86 to 54.7 for Seri 82.

Analysis of variance for grain yield, test weight, and thousand kernel weight are presented in Table 3. Although tests of significance are presented for year, date, and treatment, of primary interest is the cultivar main effect and its interactions with rust control. Grain yield and thousand kernel weight each exhibited significant cultivar main effects and interaction differences ($P < 0.05$). Test weight failed to exhibit significant differences ($P > 0.10$). This is perhaps because test weight measures the mass of a given volume of grain, which depends on packing efficiency and is affected by changes in both the size and density of kernels. Therefore, test weight is not directly related to kernel weight, and change in test weight was not considered an accurate measure of the effects of host/pathogen interaction.

Data for agronomic traits are presented in Table 4. Average grain yields of the protected plots reflected an on-farm yield potential considered appropriate for the Cd. Obregon area, approximately 5 t/ha. This on-farm yield level is in part a product of planting recommended disease-resistant cultivars. Fungicide application to these cultivars is generally neither recommended nor practiced. The difference between the yield observed during 1986-87 and 1987-88 or 1989-90 was due primarily to the experimental planting methods used, with bed planting resulting in less grain yield than solid plot planting. Grain yield as affected by leaf rust (across cultivars and averaged over years) ranged from 2.4 (Opata 85) to 27 percent (Yecora 70) lower in rusted plots. Cultivars identified as possessing hypersensitive resistance exhibited a

Table 3. Analysis of variance for data gathered at Cd. Obregon, Mexico during three years with two planting dates per cycle, planted in a three replication, split-plot, randomized complete block experimental design. Main plots represented treatment (protected vs. infected); subplots represented cultivars.

Source	Grain Yield df	Grain Yield Mean Square	Test Weight df	Test Weight Mean Square	Kernel Weight df	Kernel Weight Mean Square
Date (D)	1	20.11	1	160.40	1	1232.61
Year (Y)	2	184.36*	2	87.07	1	389.90
Error a	1	5.45	2	38.78	1	48.69
Treatment (T)	1	28.74**	1	69.26	1	571.34
Error b[1]	1	0.03	2	25.67	1	66.07
Cultivar (C)	9	8.25*	9	28.60	9	125.42*
Error c[1]	16	2.80	13	23.62	9	31.90
C × D	9	0.64	9	14.92	9	19.28
C × Y	18	3.29*	18	23.15	9	30.55
Error d	18	1.12	18	14.46	9	17.93
C × T	9	2.13**	9	33.45	9	43.84**
Error e[1]	16	0.42	8	14.03	9	4.33
C × T × D	9	0.22*	9	16.29	9	1.65
C × T × Y	18	0.29*	18	12.87	9	4.30+
Error f	18	0.09	18	15.14	9	1.59
CV (%)		4.67		4.50		3.23

[1] Complex F-test degrees of freedom calculated as described by Satterthwaite (1946).
+, *, ** P < 0.10, 0.05, and 0.01, respectively.

average of 4.7 percent lower grain yield due to the disease. Although the average yield loss was not statistically significant, protected plots always yielded more than rusted plots. The effect of rust on yield of the "resistant" cultivars may reflect loss of photosynthetic leaf area due to hypersensitive flecking or necrosis of the leaf tissue or may be due to energy expenditure by the plant in defending against other minor diseases or saprophytic fungi (Smedegaard-Petersen and Tolstrup, 1985).

Cultivars identified as possessing partial resistance to the tested races of *P. r. tritici* averaged 7.5 percent lower grain yield due to leaf rust compared to the respective protected plots. This average excludes the response of Seri 82, a cultivar also considered to exhibit some partial resistance based on one minor gene. The effect of rust on grain yield in Seri 82 (19.5 percent lower because of rust) is significant, approaching the effect observed in Yecora 70 during 1989-90. Seri 82, on the average, is 8 days later in heading than Yecora 70; therefore, Seri 82 is expected to exhibit greater loss since infection started at an earlier growth stage compared to Yecora, and the rust had approximately one more week to cause damage before Seri 82 was physiologically mature. The relationship between leaf rust development at various stages of plant growth and grain yield for a susceptible cultivar has been described by Buchenau (1970). Grain yields of the fungicide-protected partially resistant cultivars Opata 85 and Galvez 87 were not significantly different from yields of the same cultivars without protection. In contrast, grain yields of Bacanora 88, Genaro 81, and Pavon 76 each were significantly lower in response of leaf rust. Therefore, irrespective of disease response, each cultivar should be evaluated for grain yield in relation to leaf rust infection prior to its release for commercial production.

If the average percentage loss in grain yield of the hypersensitive cultivars is used for comparison, the difference in average grain yield loss between hypersensitive and partially resistant cultivars was 2.8 percent. Furthermore, it is possible to select partially resistant cultivars, such as Opata 85 and Galvez 87, which have a yield loss similar to that of the hypersensitive cultivars. The experimental conditions used for this study represent an agronomically abnormal situation because of the unusually high inoculum pressure. When resistant cultivars are grown in experimental plots, the proximity of susceptible varieties (e.g., inoculated susceptible spreader plots) provides a constant and concentrated supply of inoculum, and considerable destruction of leaf tissue of resistant cultivars may occur (Samborski and Peturson, 1960). Small plot estimations of the influence of rust on yield overestimate crop losses (Stucker, 1980). Thus, within farmers' fields, lower inoculum pressure may lessen the effects compared to those observed in this study. The expected loss in grain yield due to leaf rust on a susceptible cultivar grown under farmers' field conditions in most wheat-growing areas rarely surpasses 15 percent (Samborski and Peturson, 1960). Hence, losses on partially resistant cultivars could be expected to be minimal.

Thousand kernel weight was lower for rusted compared with protected plots by from 2.6 percent (Oasis 86) to 22 percent (Yecora 70). Nearly 80 percent ($r=0.89$; Table 5) of the variation observed in changes in grain yield could be attributed to changes in kernel weight. Thus, the contribution to lower grain yield by fewer kernels per unit area would have been slight. This relationship is probably due to the fact that the epiphytotics generally occurred after anthesis. High correlations were observed between the loss in kernel weight and AULRPC or the rate of disease growth (Table 5).

More sustainable cultivars may be bred by accumulating minor genes that convey partial resistance to leaf rust. Greater sustainability may result from several causes. First, partial genetic resistance may be more durable because of less selection pressure imposed by the host for the evolution of pathogen virulence. Second, a useful level of partial resistance requires a combination of two to four effective additive minor genes; this combination of effective genes would pose a greater obstacle to the evolution of the pathogen since the changes of multiple favorable mutations are extremely rare (Schafer and Roelfs, 1985). Stability of a pathogen population avirulence/virulence structure would result in greater durability of cultivar resistance. Third, greater cultivar durability with respect to pathogen virulence allows breeders more opportunity to concentrate their efforts towards other breeding objectives, such as yield potential, general or specific adaptation, or nutritional

Table 4. Grain yield, test weight and thousand kernel weight of ten protected and rusted spring wheat genotypes and the percent change due to infection by lea rust, averaged over two planting dates in each of three years, at Cd. Obregon, Mexico.

Cultivar	Year	Grain Yield			Test Weight			Thousand Kernel Weight		
		Protected	Rusted	Change	Protected	Rusted	Change	Protected	Rusted	Change
		g/m²		%	kg/hl		%	g		%
Oasis 86	1986–87	855	829	− 3.04	79.4	79.9	0.57	40.6	40.5	− 0.30
	1987–88	605	572	− 5.45	81.2	80.3	−1.07	44.7	42.5**	− 4.86
	1989–90	573	555	− 3.14	79.9	78.9	−1.23			
	Mean	678	652	− 3.88			−0.58	42.7	41.5	− 2.58
Ciano 79	1986–87	784	745	− 4.97	79.7	79.1	−0.86	35.6	34.9	− 2.02
	1987–88	502	460*	− 8.37	81.3	80.3	−1.19	40.5	38.7	− 4.52
	1989–90	490	480	− 2.04	78.7	78.3	−0.55			
	Mean	592	562	− 5.13			−0.86	38.1	36.8	− 3.27
Papago 86	1986–87	753	734	− 2.52	79.8	79.3	−0.63	38.0	37.2	− 2.05
	1987–88	589	525**	−10.87	80.8	80.0	−0.94	43.7	40.3**	− 7.65
	1989–90	524	516	− 1.53	80.7	80.7	0.03			
	Mean	622	592	− 4.97			−0.51	40.9	38.8**	− 4.85
Bacanora 88	1986–87	809	756**	− 6.55	80.7	79.9	−0.92	35.2	34.5	− 2.05
	1987–88	605	534**	−11.74	83.4	83.0	−0.48	38.8	36.0	− 7.29
	1989–90	542	494*	− 8.86	81.4	80.7	−0.77			
	Mean	652	595**	− 9.05			−0.72	37.0	35.3*	− 4.67
Opata 85	1986–87	793	770	− 2.90	80.8	80.3	−0.60	34.3	33.8	− 1.23
	1987–88	539	540	0.19	82.7	82.2	−0.62	39.0	36.5	− 6.41
	1989–90	568	542	− 4.58	80.1	79.9	−0.16			
	Mean	651	617	− 2.43			−0.46	36.7	35.2*	− 3.82
Galvez 87	1986–87	614	564**	− 8.14	82.3	81.8	−0.57	44.1	42.3	− 4.06
	1987–88	555	519	− 6.49	82.3	81.4	−1.15	43.2	39.1	− 9.54
	1989–90	492	486	− 1.22	81.3	80.6	−0.90			
	Mean	554	523	− 5.28			−0.87	43.7	40.7**	− 6.80
Genaro 81	1986–87	727	697	− 4.13	80.4	79.0	−1.73	39.3	36.8	− 6.29
	1987–88	582	473**	−18.73	81.7	80.0	−2.06	38.7	35.2	− 9.05
	1989–90	540	469**	−13.15	80.6	78.6	−2.40			
	Mean	616	546**	−12.00			−2.06	39.0	36.0**	− 7.67
Pavon 76	1986–87	599	572	− 4.50	82.2	81.0	−1.36	39.1	35.9	− 8.21
	1987–88	581	515**	−11.35	82.9	82.2	−0.86	42.2	40.2	− 4.74
	1989–90	494	440**	−10.93	81.1	78.2	−3.54			
	Mean	558	509*	− 8.93			−1.92	40.7	38.1**	− 6.48
Seri 82	1986–87	857	798**	− 6.88	78.8	78.2	−0.77	42.8	40.8	− 4.86
	1987–88	560	442**	−21.07	81.1	78.6	−3.04	45.2	37.5	−16.98
	1989–90	604	419**	−30.63	79.8	76.1	−4.75			
	Mean	674	553**	−19.53			−2.85	44.0	39.2**	−10.92
Yecora 70	1986–87	780	609**	−21.92	80.9	76.4	−5.57	43.9	35.5	−19.17
	1987–88	512	361**	−29.49	82.6	76.9	−6.98	47.8	36.0	−24.73
	1989–90	505	353**	−30.10	81.7	77.2	−5.57			
	Mean	599	441**	−27.17			−6.04	45.9	35.8**	−21.95
LSD (5%)		40	40					1.5	1.5	
LSD (1%)		50	50					2.0	2.0	

*, ** Pairwise differences significant at $P < 0.05$ and 0.01, respectively.

Table 5. Correlation coefficients (r) between changes in grain yield, in test weight, and in kernel weight, and area under the leaf rust progress curve (AULRPC) and logarithmic rate of disease increase for the means of ten spring wheat cultivars evaluated under rusted and protected field conditions at Cd. Obregon, Mexico during the 1986–1987, 1987–1988, and 1989–1990 crop cycles. N = 30 for all traits, respectively, except kernel weight where n = 20. All correlation are significant at $P < 0.01$.

	Grain Yield Loss	Test Weight Loss	Kernel Weight Loss	AULRPC
Test Weight Loss	0.89			
Kernel Weight Loss	0.88	0.90		
AULRPC	0.76	0.84	0.89	
Rate of Disease Increase	0.81	0.84	0.83	0.84

quality. Finally, durable genetic source of resistance reduce grain yield losses t minimal levels, thereby eliminating th need for chemical control of pathogens

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Sustainable Ag Programs Beneficial to Iowa Farmers

A decade of sustainable agriculture programs has produced substantial dividends to Iowa, but additional changes in farm management could reap even greater rewards for the state's farmers and the environment, according to a report from the Integrated Farm Management Demonstration, the Model Farms Demonstration Project, and the Big Spring Basin Demonstration Project.

Iowa farmers saved $80 million in 1989 and 1990 by reducing nitrogen fertilizer use for corn and cut fertilizer rates by more than 200 million pounds per year, according to the report by researchers at the Iowa Department of Natural Resources, University of Iowa, Iowa State University, USDA-Soil Conservation Service, and Leopold Center for Sustainable Agriculture.

Average nitrogen use declined to less than 130 pounds per acre during 1989 and 1990, compared to 145 pounds in 1985; elsewhere in the Corn Belt, nitrogen fertilizer applications remained above 140 pounds. Iowa spent about $11 million from 1980 to 1990 to educate Iowa farmers on how to use fertilizer more efficiently while maintaining yields and profits. Every dollar spent for education saved farmers $8 in fertilizer costs.

The potential for Swedish farms to eliminate the use of artificial fertilizers

Artur Granstedt

Abstract. *This paper discusses data on plant-nutrient conservation in Sweden between 1950 and 1980 and on plant-nutrient balances in conventional and alternative farming. The amounts of plant nutrients supplied in the form of artificial fertilizer in Sweden increased severalfold between 1950 and 1980. The amounts of N and P applied were four times higher than those recovered in agricultural products. This difference not only represents a loss to farmers but also a burden on the environment. This problem is a consequence of the increased separation of crop management from animal husbandry in Sweden. The flow of plant nutrients through the agroecosystem can be represented as follows: Artificial Fertilizers-> Crop Production-> Animal Husbandry-> Losses (air, water, or immobilization).*

This paper suggests that all farms in Sweden can operate effectively without relying on applications of highly soluble plant nutrients. By recirculating plant nutrients in manure and cultivating nitrogen-fixing species, the need for artificial fertilizers can be eliminated while minimizing nutrient losses and their associated adverse effects on the environment. Successful alternative farms provide practical examples of how a farming system can eliminate its dependence on applications of highly soluble plant nutrients by stressing effective nutrient economy and biological activity. The strategies they use include: matching animal management practices to the farm's own production of feed, thereby reducing net removal of plant nutrients per unit area (in Sweden 0.6-0.8 animal units per ha); minimizing nutrient losses through careful manure management and by using cover crops; and supplying N by nitrogen-fixing ley species, and P and K by soil weathering and by applying supplementary soil improvement materials.

Key words: Ecosystems; case studies, nitrogen, nitrogen fixation, organic farming, Sweden

Introduction: The increasing loss of plant nutrients in Swedish agriculture from 1950 to 1980

The Swedish farming system comprises about 2.9 million hectares of arable land divided among about 101,000 farms (Yearbook of Agricultural Statistics, 1989). The agricultural system underwent a dramatic structural change between 1950, when 25 percent of the population worked in farm-related areas, and 1980, by which time the figure had dropped to 2 percent. Earlier, animal husbandry and crop farming were practiced together on every farm. Gradually, however, the situation began changing, as was the general case for agriculture in the West; certain regions began specializing in grain production while others specialized in animal husbandry. The breakdown of the original structure occurred hand in hand with the consolidation of smaller farms into larger ones.

This reorganization was made possible by the increasing availability of inexpensive plant nutrients in the form of artificial fertilizer. As shown in Figure 1, the amounts of plant nutrients applied in ar tificial fertilizer increased substantiall between 1950 and 1980. However, thes increases in plant-nutrient input wer not associated with corresponding in creases in agricultural production. Fo example, in 1980 the amounts of N an P applied were four times as high as th amounts ending up in agricultural foo products (e.g., livestock, cereals, vegeta bles) (Jansson, 1983). Likewise, the inpu of K was eight times as high as the out put in the form of farm products. Thi difference between supply and remova to a large degree represents a loss fron the agroecosystem.

Nitrogen losses to the atmospher account for about half the total losse (Jansson, 1983) and are primarily associ ated with intensive animal husbandry However, about half the losses are attrib utable to surface runoff and leaching, th latter seriously contaminating drinkin water in some areas.

To deal with the overabundance o manure produced on livestock farms, th manure often is spread over fields in ex cessive amounts, leading to high leach ing losses of P, which in turn can caus the eutrophication of surrounding lake and streams (Andersson, 1986). Actua losses of N are larger than indicated i Figure 1. Other sources include atmos pheric deposition and biological fixatio as well as the N present in feed. N losse have been estimated at 100 kg/ha/yea Large regional differences exist, how ever, with the largest losses occurring i areas with intensive livestock farming i southern Sweden.

The difference between supply and re covery of N is even larger in the othe Scandinavian countries, being highest i Denmark. Fisheries in both the Balti and the Kategatt are considered to b threatened by algal blooms and period of oxygen deficiency resulting from th

Artur Granstedt is State Extension Specialist in Alternative Agriculture, Department of Research Information, Swedish University of Agricultural Sciences, Uppsala, Sweden.

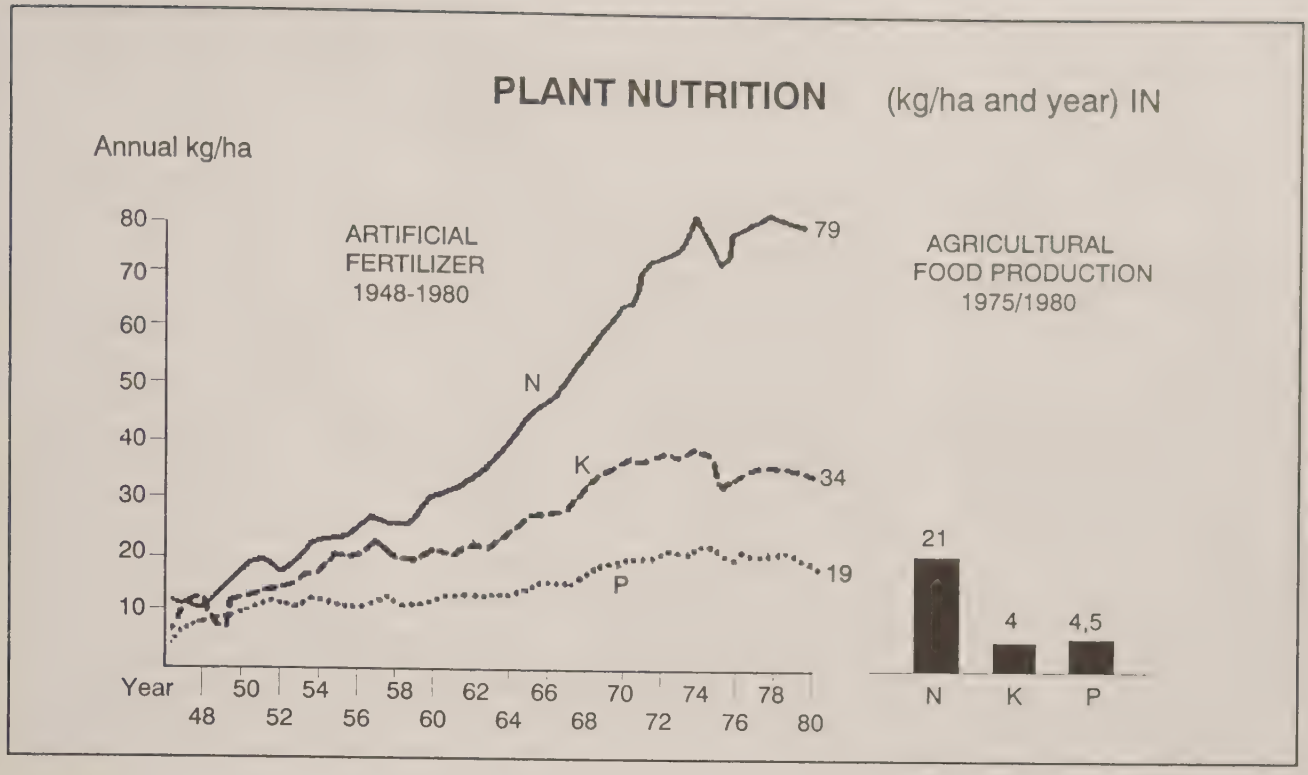

Figure 1. Additions of nitrogen, phosphorus, and potassium, in the form of artificial fertilizer, and removal through sale of cash crops and animal products for Swedish agriculture. Mean losses (the difference between inputs and outputs) have increased as the degree of farm specialization (i.e., emphasis placed on either crop production or animal husbandry) has increased. Losses are primarily to the atmosphere, surrounding lakes and streams, and the soil.

decomposition of organic material. The farm industry bears part of the responsibility for this serious environmental problem, and in both Sweden and Denmark programs have been initiated with the aim of reducing the agricultural N load by half (Swedish Environmental Protection Agency, 1990). Another important aspect of the plant nutrient problem is that such resources are nonrenewable and thus must be conserved.

In Sweden and other countries, the increasing losses of plant nutrients from arable land can be attributed mainly to the above-mentioned structural reorganization and the associated increasing reliance on artificial fertilizers. In Sweden, about 80 percent of the cultivated area is used for feed production, whereas animal husbandry has become concentrated to the point where a small number of large farms account for most of the production. This concentration has been most pronounced with regard to swine, poultry, and egg production. In Sweden, 2.4 percent of the farms account for 65 percent of pork production (Yearbook of Agricultural Statistics, 1989). As a consequence, crop farmers must purchase plant nutrients in the form of artificial fertilizer. A portion of these nutrients ends up on livestock and swine farms in the form of feed. Of the plant nutrients present in feed, the proportion recovered in dairy and meat products varies from 10 to 40 percent, depending on the type of animal and nutrient. Most of the remainder is lost. The extent of the loss depends greatly on the level of animal production in relation to the cultivated field area, as will be explained in more detail below.

At the Division of Plant Nutrition, Swedish University of Agricultural Sciences, a series of case studies concerning the nitrogen-supply dynamics on organic farms has recently been completed (Granstedt, 1990a). In connection with this project, studies have also been conducted on the supply dynamics of other plant nutrients on organic farms. The aim has been to improve our knowledge to more effectively advise farmers who no longer rely on artificial fertilizers. One outcome of this work has been the development of a technique for calculating plant nutrient balances. The following sections present several examples of plant-nutrient balances at the farm level.

Methods for calculating plant-nutrient balances

Plant nutrients generally are imported to a farm in the form of purchased fertilizers and animal feed. The export of plant nutrients occurs with the sale of plant and animal products. The amounts involved are determined on the basis of information regarding purchases, sales, and nutrient content, also taking account of any changes during storage. In this paper the nutrient contents were calculated using standard feed analysis (Eriksson et al., 1972) and foodstuff analysis (Statens Livsmedelsverk, 1981) techniques. The balances for supply and removal (input and output) for the whole farm are calculated in kg/ha per year.

In addition to the nutrients supplied and removed through purchases and

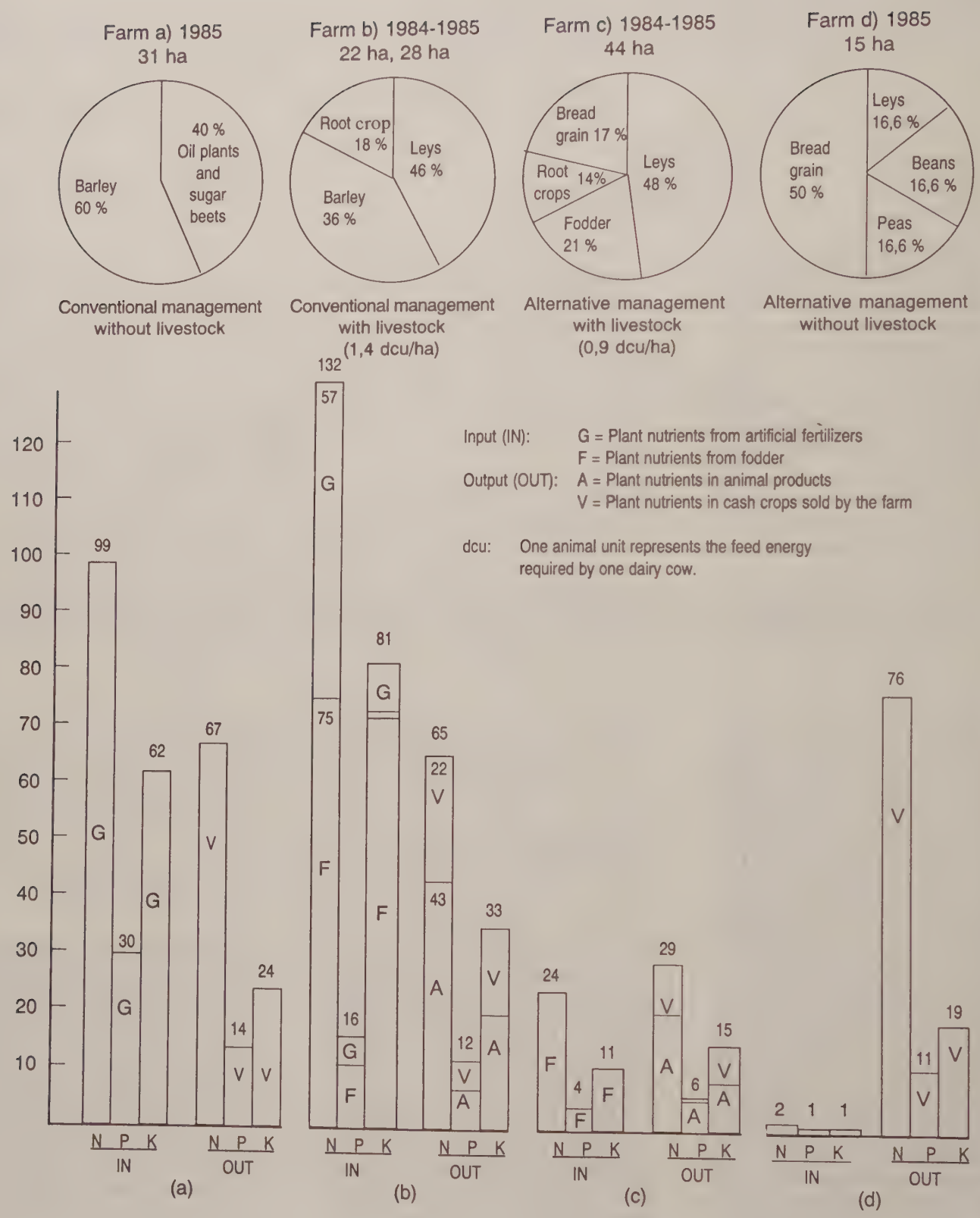

Figure 2 (a-d). Inputs and outputs of N, P, and K (kg/ha/year) for two farms with conventional management a) without and b) with livestock, and two farm practicing alternative management c) with and d) without livestock. In addition, the proportions of the total farm area allocated to various kinds of production ar shown above.

sales, there is a steady flow of nutrients within the farm among the soil, plants, and animals. Harvest data and production statistics for dairy and meat products (growth) as well as analytical results make it possible to quantify this within-farm flow.

Nutrient flows also occur to and from the atmosphere, water, and soil as a result of physical, chemical, and biological processes, some of which are influenced by cultivation measures. Thus the estimation of balances for supplied and removed nutrients on the basis of purchases and sales has inaccuracies. Losses can be greater than the balances would indicate. N is also supplied through atmospheric deposition and biological fixation. Where amounts leaving the system are substantially greater than those supplied, the situation can be attributed to a net removal from the soil reserves or a net surplus from the atmosphere (for N).

Plant-nutrient balances for various types of conventional farm operations

Figure 2a illustrates the plant-nutrient balance on a conventional grain farm in Kristianstads County, in southern Sweden. The amounts of plant nutrients purchased in the form of artificial fertilizers exceed the amounts exported in the form of grain by 32, 16, and 38 kg/ha/year for N, P, and K, respectively. Because the soils consist of fine and moderately coarse sands, leaching risks are high. Of the N supplied, 62 percent is removed in the form of crop, while the remainder is considered lost. In reality, supplied nutrients are continuously being exchanged for nutrients in the soil. The figures constitute a measure of the exchange in relation to the supply. If N fallout is also taken into account (15 kg/ha/year), there will be a corresponding increase in the estimated losses. N-balance studies on conventional farms located on clay soils have shown that N conservation on such farms is better than in the above example.

Figure 2b illustrates the balance for supply and removal on a conventional, intensively managed cattle farm in the same area and with the same cultivation conditions. Here feed is bought to supplement the farm's own production. Plant nutrients are purchased in the form of both feed and fertilizer, with purchased amounts exceeding amounts in the sold products by 67, 4, and 48 kg/ha/year for N, P, and K, respectively. The actual loss of N, taking into account the contributions of atmospheric deposition and biological fixation by ley crops with clover and lucerne, was estimated to be 100 kg/ha/year.

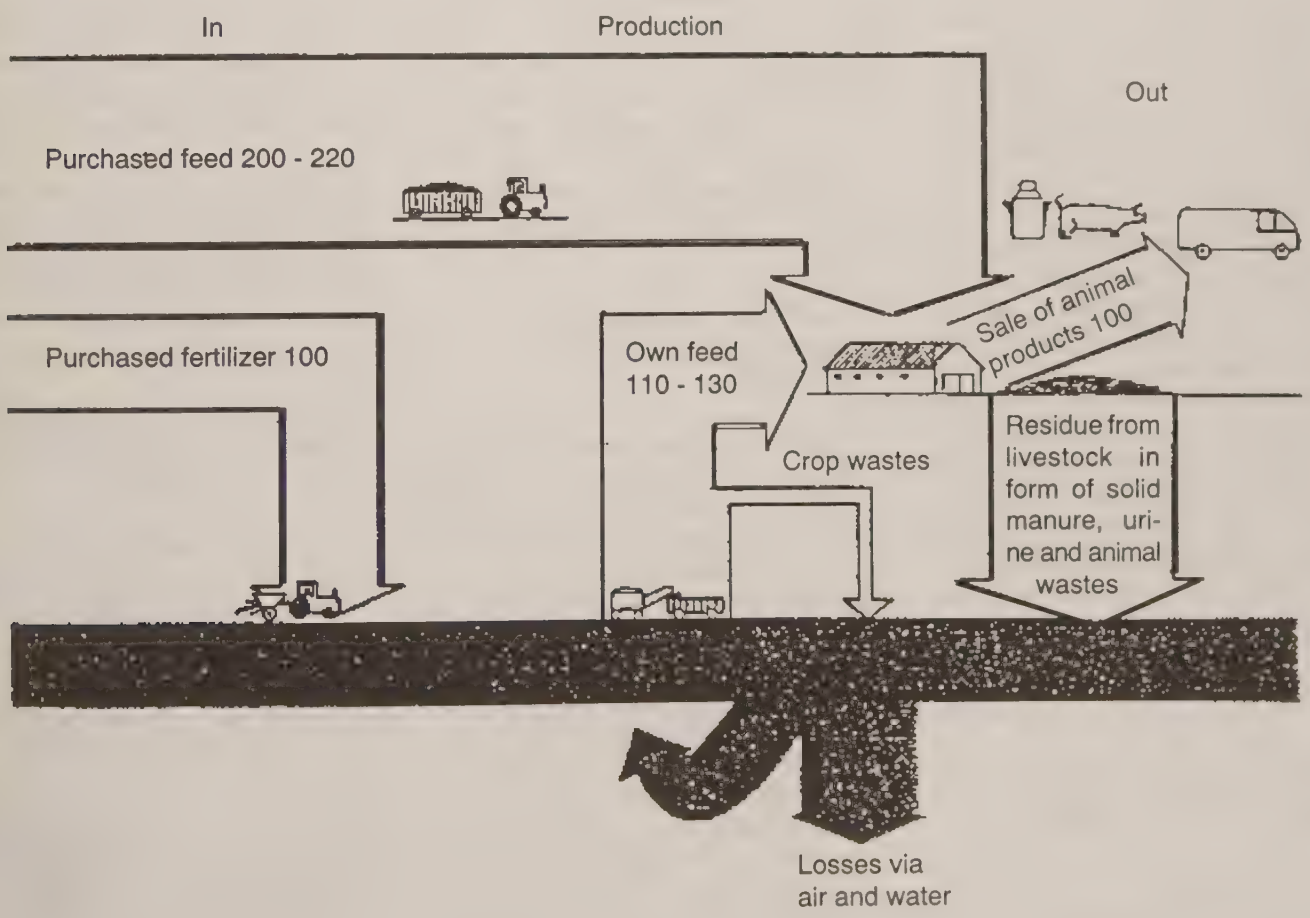

Figure 3. Example of the annual supply and export of nitrogen (in kg N/ha) calculated for an average year for a farm in Blekinge, in south Sweden, with 2 animal units per ha. The farm has 50 ha in crop production, 50 milk cows, 22 heifers, 10 sows, and 680 fattening pigs.

Figure 3 presents the N-balance for supply and removal on a pig farm in Blekinge. The management intensity here is two animals per hectare, the upper limit for many farms today. The difference between supplied N in purchased feed and fertilizer and N removed through sales of animal products (milk and meat) is 200 kg/ha/year. Again, the actual loss of N is even greater. Atmospheric contributions and possible storage in the soil were not taken into account.

The examples show that plant nutrients are introduced into animal farms via fertilizers and feed purchased from intensively fertilized grain farms. Comprehensive inventories have also shown that animal producers make supplementary purchases of plant nutrients in the form of artificial fertilizers (Andersson, 1986). The example presented is representative of the situation on a large proportion of the country's animal farms. In extreme cases, the differences between supply and removal are much larger, both in Sweden and in other countries. In Halland County, in southwestern Sweden, where the average management intensity is over one animal per hectare, purchases of N, P, and K in fertilizer are higher than the mean for the country as a whole (Andersson, 1986). The lower proportion of ley on pig farms as well as the higher precipitation and very permeable soils further hamper efforts at conserving plant nutrients in these intensively managed areas.

The examples illustrate the flow of essential nutrients through today's highly specialized farms: Artificial Fertilizer-> Crop Production-> Animal Husbandry-> Losses (to air, water, or immobilization)

If we can halt this loss and its environmental consequences, as we must, then the need to purchase artificial fertilizer should decrease to a corresponding degree.

Farming without artificial fertilizers: Is it possible?

Plant-nutrient balances for various alternative farms

In alternative forms of crop production, such as organic-biological, natural, and biodynamic farming, neither artificial fertilizers nor highly soluble plant nutrients are used. During recent years, the area under alternative agriculture has increased to the extent that it now accounts for more than 1 percent of the total arable land area (> 30,000 ha). In Sweden, where alternative farming is regulated, the only soil amendment allowed--and then only after an exemption is obtained after conferring with an extension agent--is potash-magnesia. Limited purchases are allowed of organic fertilizers obtained from a variety of plants and animals. Supplementation with soil conditioners such as stone dust and phosphorite is also permitted. The steady increase in the area under alternative forms of farming has led to a concomitant rise in interest in this form of management, owing to its potential to conserve resources and protect the environment (Granstedt, 1990b) and to improve the nutritional quality of agricultural products (Dlouhy, 1981; Pettersson, 1982). Is it possible to achieve self-sufficiency with regard to plant nutrients, especially nitrogen, while maintaining satisfactory levels of productivity and profits, and could such a system be applied at the community level?

Alternative strategies for supplying plant nutrients at the farm level

The plant nutrient balances for some conventionally managed farms are presented in Figures 2a and 2b. Their respective management intensities were 0, 1, 4, and 2 dairy cow units (dcu)/ha. Figure 2c illustrates the closing balances on a biodynamically managed farm in Skåne, located in the same area and having the same soil characteristics as the farms treated in Figures 2a and 2b. This farm has been under biodynamic production since 1976. Here the amount of plant nutrients sold is greater than the amount bought. Some nutrients enter the farm in the form of purchased feed. Animal production with 0.9 dcu/ha is higher than the average for the country as a whole, which is 0.7 dcu/ha. A net production of 5 kg/N/ha is obtained without having to apply artificial fertiliz ers. Figure 2d shows an alternativel managed farm dealing exclusively wit crop production.

The ideal alternative farm should con tain both plant and animal productio components. As the level of animal pro duction decreases on the farm, the nitro gen exported in the form of plant prod ucts increases in direct proportion to th decrease in demand for animal feed. Thi increase can be as high as fivefold o a self-restocking dairy farm. A balanc point can be reached, with the highes possible recycling and a production leve corresponding to the average productio needs of cash crops and animal product in the country (Granstedt, 1990a). Fig ure 4 presents the N balance calculate on a biodynamic farm in Järna, with management intensity of 0.5-0.6 dcu/ha Here we have an example of a farm tha has been run biodynamically under cen tral Swedish conditions since 1968. A comparison can be made with the plan nutrient balance for the Swedish farm system. As can be seen, the productio of N, P, and K is similar to the averag for the country and corresponds wel with the levels of production and con sumption of agricultural food products The difference is that on the biodynami farm no plant nutrients are introduce in the form of artificial, soluble fertilizer What requirements must be fulfilled t practice this type of farm management

Adjusting the level of animal production to meet the area's plant-nutrient needs

Animal production on a farm or on group of cooperating farms needs to b adjusted so that the plant nutrients enc ing up in manure and urine can be re turned to the farm (60 to 90 percent o the nutrients in the feed). Animal pro duction on each farm should at leas equal the mean level for conventiona farms in Sweden (0.7 dcu/ha). With 7 to 80 percent of the area being used t produce feed for the animals on the farm the outflow of nutrients associated wit product sales would be reduced to be tween 4 and 7 kg/ha of P and K. In turn the need to compensate for the expo of these nutrients would decrease by

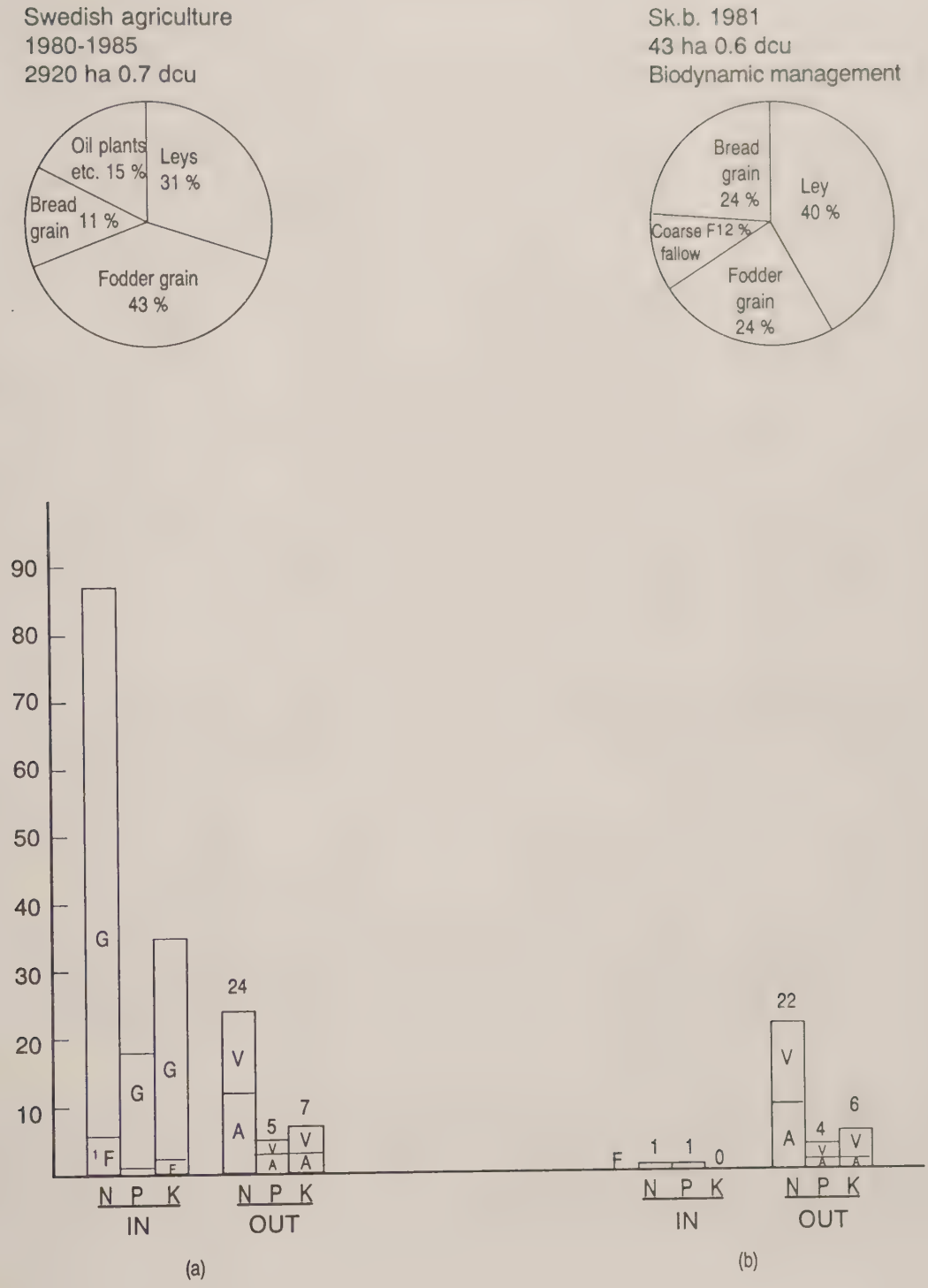

Figure 4. Input (F=feed, G=artificial fertilizer) and output (A=animal products, V=cash crops) of the plant nutrients N, P, and K (kg/ha/year) for Swedish agriculture in total compared with a biologically balanced farm self-sufficient in feed and fertilizer. In addition, the proportions of the total farm area allocated to various kinds of production are shown above.

corresponding amount. Purchasing bone meal is one way to recirculate a portion of the nutrients that have left the farm. In addition, the composting of sorted household garbage from urban areas is a recycling measure of great potential.

Minimizing losses

To minimize N losses it is necessary to adopt a manure management strategy (composting, in the case of biodynamic farming). Solid farmyard manure should be spread in fairly large amounts, after which it must be quickly worked into the soil, at the right time. A large proportion of cover crops also is essential; leys normally constitute about 50 percent of the cultivated area on alternative farms. Soil

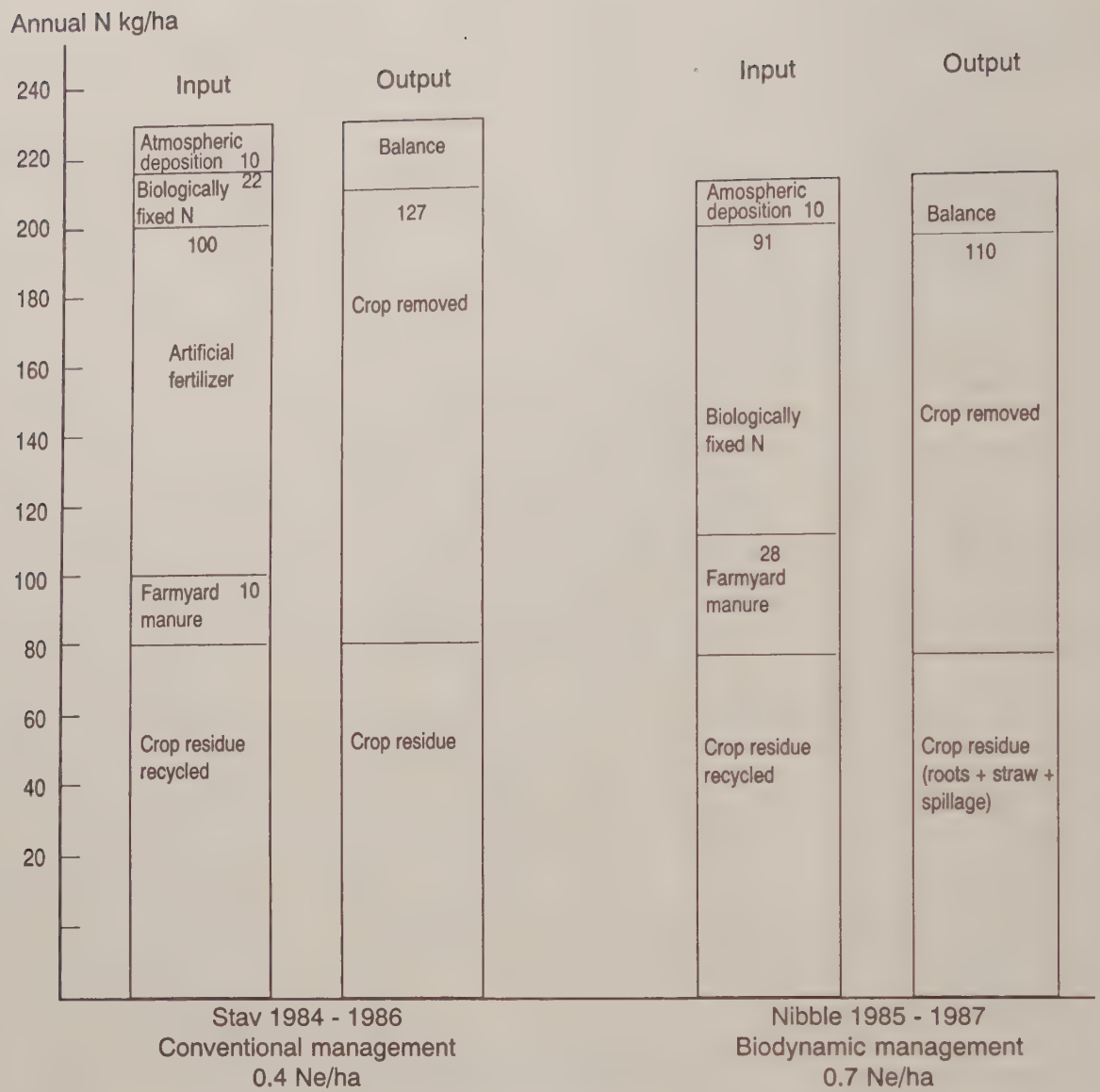

Figure 5. Nitrogen balance. Average nitrogen supply with and without artificial nitrogen from all lots for two farms in six- and seven-year rotations with comparabl conditions in Järna (central Sweden). Input and output were calculated from the average values for several plots in the crop rotations on the farms. The values ar based on measurements and calculations of the changes in mineral nitrogen in the soil, the nitrogen taken up by the crop, the input of fertilizers including the nitroge derived from crop residues, and the action of nitrogen-fixing legumes. The detected losses of mineral nitrogen (in the balance) from the soil profiles (0-90 cm) durin the winter period were higher on the conventionally managed farm. About 35 percent and 45 percent of the crop rotation were leys on the respective farms. Th proportion of legumes and the contribution of nitrogen from legumes were greater for the Nibble farm. In this instance, crop production by the farm fulfills it nitrogen requirements (Granstedt, 1990a).

N studies (Granstedt, 1990a) have shown that, when soil N is in limited supply, N utilization efficiency is high. As a consequence, the amount of leachable residual N is relatively low on alternative farms.

Enhancing the contributions of nitrogen-fixing plants and soil weathering to the soil nutrient pools

Nitrogen. N is supplied through biological fixation, with the amounts supplied corresponding to the amounts leaving the farm in the form of sold products. Figure 5 shows data from a conventional farm and a biodynamic farm. The example involves two farms in Sörmland (Järna) with nearly identical cultivation conditions (a medium clay containing 2.5 to 4 percent organic matter in the topsoil and heavy clay in the subsoil) and similar crop rotations. A high degree o nutrient recycling with manure and le cultivation made it possible to kee losses low on both farms. The Nibbl farm has been under biodynamic pro duction since 1967. Differences in yiel were moderate during the study period On the biodynamic farm N was supplie through fixation by the nonfertilized le guminous ley crops.

Based on these studies, the followin

conclusion was reached: "If conditions are conducive for high biological nitrogen fixation and if the nitrogen-supplying capacity (mineralization) can be regulated, then alternative biodynamic farms can obtain the same level of productivity as conventional farms. Such conditions can be met by practicing legume dominated ley farming in which legumes account for 30-40 percent of the cultivated area and are positioned suitably in the rotation and by recycling the nitrogen in composted manure" (Granstedt, 1990a).

Other nutrients. Owing to the low rate of net removal on the biodynamic farm in Figure 4, the amounts of nutrients removed were fully replaced by minerals in the inorganic and organic soil reserves and through weathering.

It was possible to identify nine points on the soil map from 1965, two years before converting over to conventional farming, and compare their topsoil soluble P contents with those measured in 1984. Despite the relatively low P values (soluble P-AL 2 to 19 mg/100 g soil, in 1984) obtained for the soils studied at Järna, P levels did not decline during this time (years 1965-1984). The steady phosphorus levels were certainly due to a large extent to subsoil contributions, which were enhanced by the cultivation of crops with deep root systems. The greater recirculation of plant nutrients led to a reduction in the removal of macronutrients in sold products.

Long-term studies have shown that the use of organic fertilizers leads to increases in soil fertility in the form of increased soil biological activity, greater earthworm abundance, a higher organic matter content in the subsoil, and improved physical characteristics of the soil (Pettersson and Wistinghausen, 1977; Beck, 1986). On most Swedish soils the weathering process in connection with a high biological activity is enough to replace a net export of 5 kg P and K per ha per year. Long-term studies on Talhof in Baden-Würtenberg, one of the oldest biodynamic farms in Europe (established in 1930), have given similar results (Kaffka et al., 1988). In the future, in soils where the bound-mineral reservoir is low, phosphorus can be supplied through enrichment with soil conditioners. Such soil conditioners include phosphorite, phosphorus containing lime, potash feldspar, and biotite.

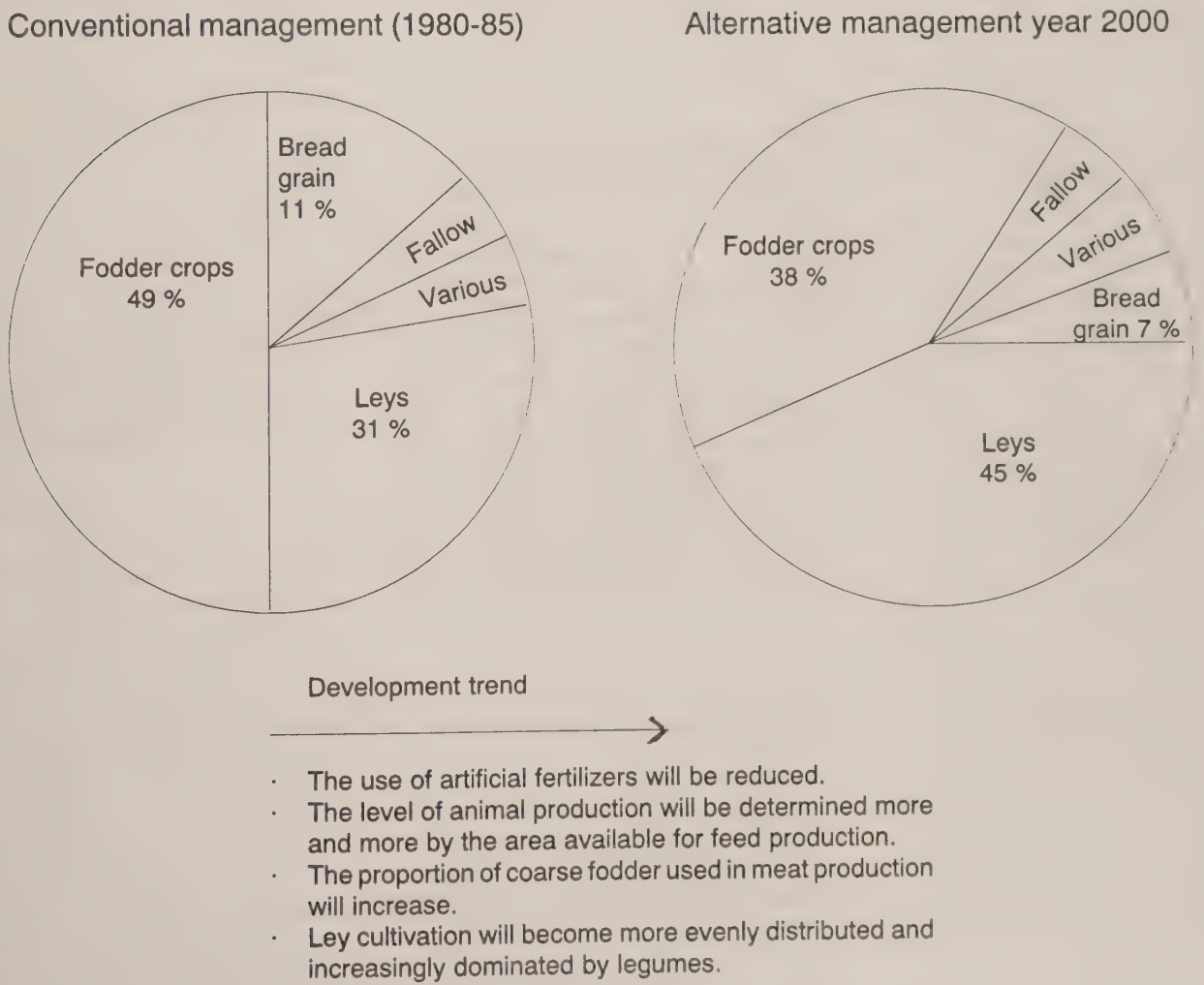
Conventional management (1980-85)
Bread grain 11 %
Fodder crops 49 %
Fallow
Various
Leys 31 %
Alternative management year 2000
Fodder crops 38 %
Fallow
Various
Bread grain 7 %
Leys 45 %
Development trend
· The use of artificial fertilizers will be reduced.
· The level of animal production will be determined more and more by the area available for feed production.
· The proportion of coarse fodder used in meat production will increase.
· Ley cultivation will become more evenly distributed and increasingly dominated by legumes.

Figure 6. Proportions of the total cultivated area allocated to various types of production (Granstedt, 1983; Granstedt, 1990b).

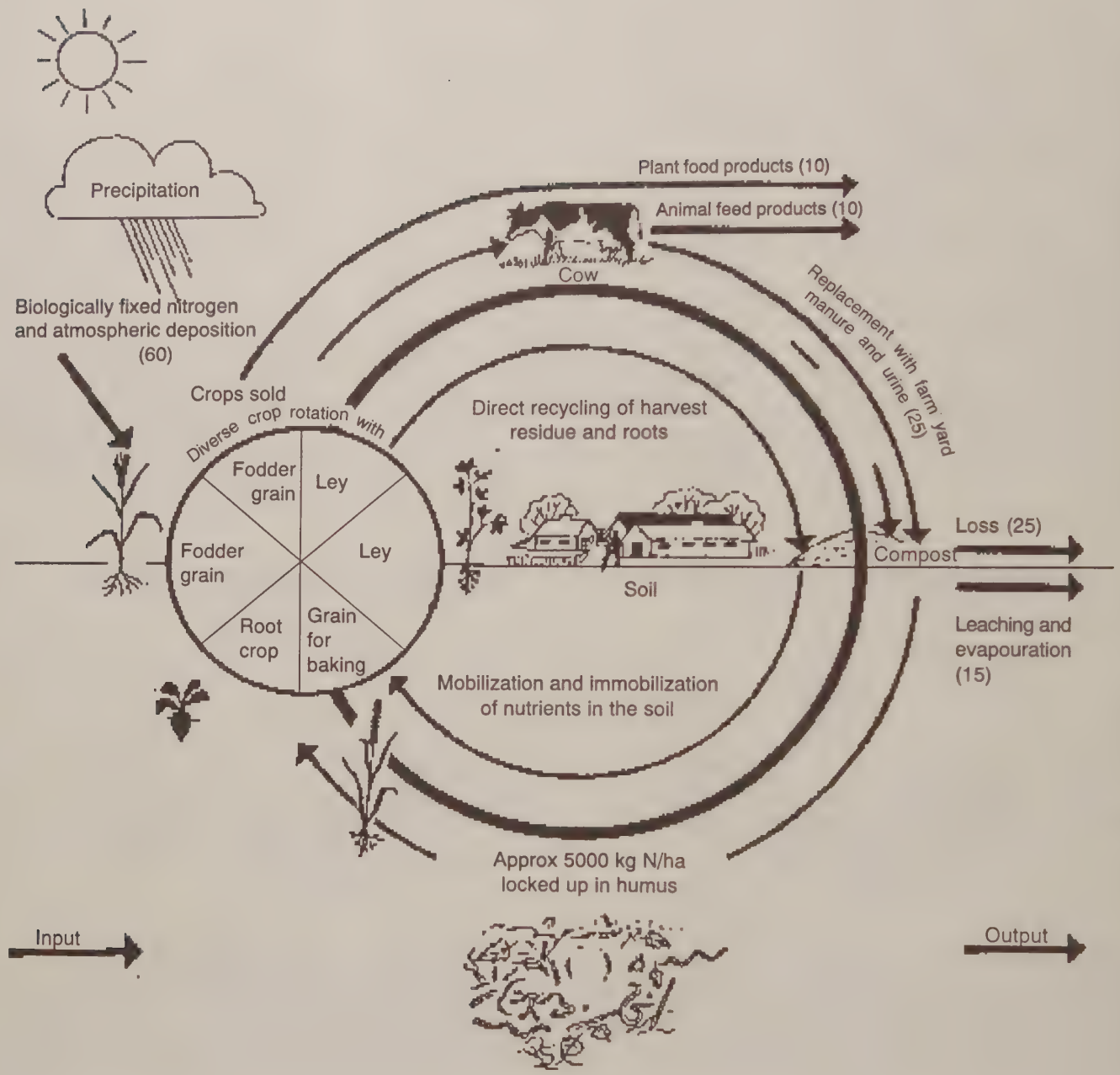

Figure 7. Cycling of plant nutrients (kg N/ha/year) on a farm self-sufficient with regard to fodder and manure (farm sk.b in Figure 4b). The calculations are based on data from Granstedt (1990a).

Research is under way with these preparations to provide advisors with the knowledge they need to make recommendations to farmers and gardeners. In the future we will also recycle more of the nutrients in garbage from urban areas, as mentioned earlier.

Implications for Swedish agriculture

Calculations have been made to quantitatively describe a biologically optimal Swedish agricultural system tailored to the country's meat, dairy product, bread grain, and vegetable needs (Granstedt, 1983). The model is based on the assumption that the land area under production will remain the same and that the farming units will be managed in an ecologically sound manner, with the farms supplying all of their own feed and fertilizer needs. It is also assumed that on average the yield of grain on biodynamic farms will be 20 percent lower than that on conventional farms and that feeds predominately will be roughage. In addition, the area cultivated with legume-dominated ley crops will be larger and will contain a wider variety of crops. In this way it will be possible to conserve the limited resource stores, with a minimum of losses to the environment, and to preserve the field as the foundation for self-sufficient farming. Figure 6 shows the results of this calculation for the conversion of all Swedish agriculture to alternative systems.

Conclusions

The ever-increasing losses of plant-nutrient capital can be attributed to the increasing segregation of crop and animal management while, at the same time, about 80 percent of the harvest is used for animal feed. The main flow of plant nutrients can be described as follows: Artificial Fertilizers->Crop Production->Animal Production->Losses (to air, water, or immobilization).

The examples of nutrient balances from alternative agriculture show that it would be possible to operate all of the farms in a country such as Sweden without having to supply highly soluble nutrients, if the above-described outflow could be eliminated. Recycling of plant nutrients, nitrogen fixation, and soil conditioners together can eliminate the need for artificial fertilizers while also minimizing losses and the adverse environmental effects associated with them.

The practical application of alternative farming methods has shown that by emphasizing nutrient conservation and biological activity a farm can be run effectively without having to rely on the use of highly soluble artificial fertilizer. By adjusting animal production to meet regional plant nutrient needs, the net removal of nutrients per unit area, as well as nutrient losses, can be kept low. Losses can also be minimized through good manure management and by the extensive cultivation of cover crops. Nutrients can be supplied through nitrogen fixation by leguminous ley crops as well as through soil weathering and the supplementary use of soil conditioners. The principles of the self-sufficient farm as a basis for agriculture are described in Figure 7.

It is possible to run a biologically optimized farm tailored to the markets for plant and animal products. This type of management requires that animal husbandry be more evenly distributed among farms and regions, that animals be given more coarse feed from legume based leys, and that the level of animal production be adjusted so as to meet the plant-nutrient needs of the area under cultivation. In exclusively agricultural areas in southern Sweden, green-manure leys can be substituted for grain crops during transition periods, thereby reducing the chances for development of a grain surplus.

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Green leaf manuring as an alternative nitrogen source for castor bean on marginal soils of India

G. Subba Reddy, B. Venkateswarlu, K. P. R. Vittal, and G. R. M. Shankar

Abstract. *Chemical fertilizers are used only in a limited way under dry farming conditions in India because of their high cost and the risk of crop failures due to drought. Several alternative strategies are being evaluated to reduce the cost of supplying N to castor bean without adversely affecting yield. We report the results of a two-year study on the possible replacement of fertilizer nitrogen by green leaves from* Leucaena leucocephala *for production of castor beans on a low fertility Alfisol. Bean yield and dry matter production were significantly higher when 50 kg N/ha was applied as green leaves compared with 50 kg N/ha as urea. Among substitution levels, 37.5 kg N/ha as green leaves at planting followed by 12.5 kg N/ha as urea at 45 days after planting was found to be the most effective combination. Across all the substitution levels, addition of nitrogen as green leaves at planting was found to be better than application at 45 days after planting. Nutrient and water use efficiencies were higher when the N was applied as green leaves compared to urea. Nitrogen use efficiency was higher for green leaves than for urea under limited rainfall conditions. The overall data indicated that 75 percent of the fertilizer N requirement of castor bean can be supplied by leaves of* Leucaena leucocephala *when applied at planting.*

Key words: green leaf manuring, nitrogen fertilizer, castor bean, Alfisol

Introduction

Castor bean (*Ricinus communis* L.) is an important non-edible oilseed crop in India. It is grown mainly under dryland conditions in four states on 1.88 million hectares, yielding about 1.27 million tons of beans annually. The average yields of this crop have remained stagnant for many years, although significantly higher yields have been obtained on selected farms where intensive management is practiced. An important reason for the current low productivity is that the crop is grown on low fertility marginal lands with poor management. The farmers who grow this crop are generally poor and do not apply the recommended level of nitrogen fertilizer necessary to obtain maximum economic yields. Thus, there is a need to develop alternative strategies for supplying low-cost N to castor bean without affecting the productivity.

In the last decade there has been renewed interest in the use of organic N sources not only to reduce the need for manufactured N fertilizer, but also to enhance and maintain soil productivity (Hornick and Parr, 1987; Parr and Colacicco, 1987; Sharma and Mitra, 1990). Organic materials not only supply plant nutrients but also improve soil physical properties like aggregate stability, water-holding capacity, and bulk density (MacRae and Mehuys, 1985). Although a great deal of work has been reported on the utilization of green leaf and green manuring technologies for rice farming (IRRI, 1987), relatively little attention has been given to rainfed crops. For example, there have been few studies on castor bean, although it is one of the main non-edible oilseed crops in India with long duration (requiring about 6 months from planting to harvest) and high nutrient requirement. Furthermore, agroforestry systems are becoming increasingly popular in tropical regions, where multipurpose nitrogen-fixing trees are grown in hedge rows and the arable crops in the alleys (Kang et al., 1981; Singh et al., 1987). Several such systems are under evaluation in India, with the prunings from the tree used as fodder, mulch, or organic fertilizer (Singh et al., 1987). As much as 9.5 t/ha of fresh prunings can be produced annually for such uses (Narkhede and Ghugare, 1987). Therefore, we undertook a comprehensive two-year study to evaluate the potential of green leaves from *Leucaena leucocephala*, a nitrogen-fixing leguminous tree, as a source of supplementary N for castor bean in a low-fertility Alfisol. The study varied the possible fertilizer substitution level and time of incorporation in the soil so that an integrated nutrient supply package can be developed that is intended to be sustainable.

Materials and methods

The experimental site was located near Hyderabad, in Peninsular India, on a typical Alfisol with a depth of 50 cm and water-holding capacity of 50 to 100 mm. The soils are low in total N (0.05 percent), medium in available P (10 kg/ha), and high in available K (120 kg/ha),

G. Subba Reddy is Agronomist, B. Venkateswarlu is Microbiologist, K. P. R. Vittal is Soil Scientist, and G. R. M. Shankar is Statistician, Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad 500 659, Andhra Pradesh, India.

with near neutral pH (6.5). The experiment was conducted during the rainy seasons of 1988 and 1989. The rainy season in this part of India extends from June to October, but castor bean is a long season crop producing beans from different spikes that mature at regular intervals. Primary, secondary, tertiary, and quaternary spikes develop sequentially and are harvested at different times, with the final harvest extending to January. The reproductive period thus extends beyond the rainy season. In this study, the crop was planted on June 15, 1988, and July 1, 1989, and harvesting continued until January in both years.

There were 9 treatments, including five levels of substitution for fertilizer N (0, 25, 50, 75, and 100 percent), which were imposed either at planting or 45 days after planting (DAP). The substitution was made within a total 50 kg N/ha, which is the recommended application rate in the region (Table 1). Urea was the fertilizer N source, while freshly pruned leaves and small twigs of *Leucaena leucocephala* (containing an average of 3.32 percent N on a dry weight basis) were the organic N source. The green leaves and twigs were incorporated as a side dressing that was banded at 10 cm soil depth. At planting 13.2 kg P/ha was applied in all plots as a basal dressing. The treatments were compared in a randomized block design with four replications with a plot size of 20 m^2.

Table 1. Details of the treatments.

T_1	Control (No nitrogen)
T_2	50 kg N/ha as green leaves (25 kg N/ha at planting and 25 kg at 45 DAP)
T_3	50 kg N/ha as urea (25 kg N/ha at planting and 25 kg at 45 DAP)
T_4	12.5 kg N/ha as green leaves at planting and 37.5 kg N/ha as urea at 45 DAP
T_5	25 kg N/ha as green leaves at planting and 25 kg N/ha as urea at 45 DAP
T_6	37.5 kg N/ha as green leaves at planting and 12.5 kg N/ha as urea at 45 DAP
T_7	12.5 kg N/ha as urea at planting and 37.5 kg N/ha as green leaves at 45 DAP
T_8	25 kg N/ha as urea at planting and 25 kg N/ha as green leaves at 45 DAP
T_9	37.5 kg N/ha as urea at planting and 12.5 kg N/ha as green leaves at 45 DAP

Dry matter accumulation, leaf area index, and nutrient uptake were recorded at different phenological stages while the beans were harvested, depending on the maturity of different spike orders, and at final harvest. The data was subjected to standard statistical analysis.

The rainfall pattern during 1988 and 1989 growing seasons (from 24 to 52 standard meteorological weeks) is presented in Figure 1. A total of 513 mm rainfall was received in 1988 in 40 rainy days. The distribution was quite uniform up to 90 DAP, after which there was a dry period that lasted more than six weeks. This dry spell adversely affected the maturation of primary spikes and flowering of the secondary spikes. However, a 28 mm rainfall occurred during the last standard week (week 52), which

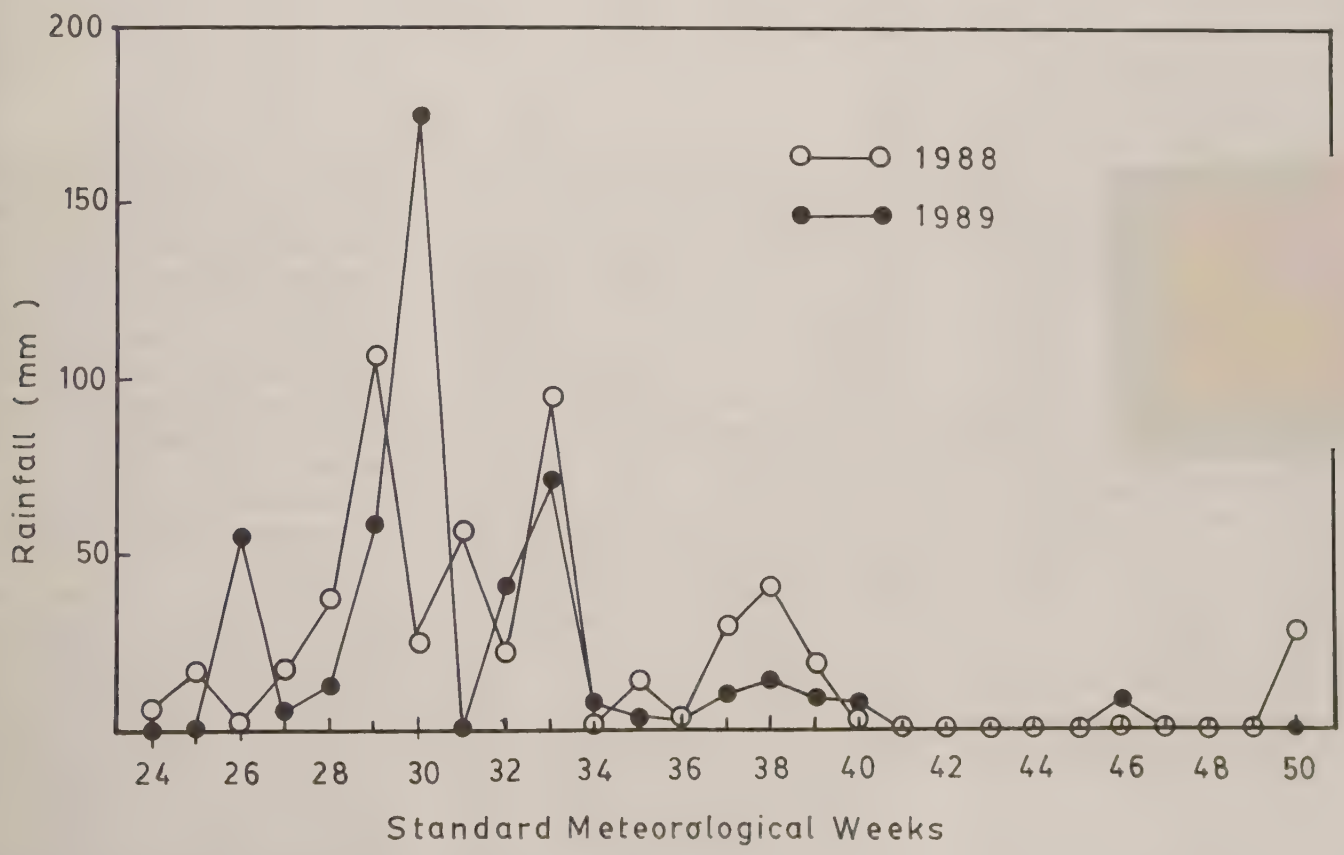

Figure 1. Rainfall pattern at the experimental site during 1988 and 1989.

provided the additional bean yield from the quaternary spikes. During 1989, the seasonal rainfall was only 485 mm in 26 rainy days. A drought of 15 days during weeks 35-37 affected the rate of emergence of primary spikes, while the second dry period from week 42 onward affected the yield of secondary and tertiary spikes.

Results

The bean yield of castor bean was more than doubled by 50 kg N/ha applied either as green leaves or urea in both 1988 and 1989 (Table 2). Furthermore, the yields obtained with 50 kg N/ha as green leaves (T_2) were higher than 50 kg N/ha as urea (T_3). The highest bean yields, however, were recorded when 37.5 kg N/ha was applied as green leaves at planting followed by 12.5 kg N/ha as urea at 45 DAP (T_6) in both years. The data for yield components, including spike length, number of capsules/m^2, and test weight (1000 seed wt) followed a pattern similar to that of bean yields for different treatments. Number of capsules/m^2 in T_6, T_3, and T_2 were 261, 247, 243 and 120, 124, and 116 respectively in 1988 and 1989. Nitrogen in the form of green leaves generally caused larger bean size (test weight in T_2 was 246 g while it was 238 g in T_3 in 1989), which contributed to higher bean yield. The relative contribution of different spike orders to the total bean yields followed a similar trend in both years, with the highest yield coming from primary spikes.

Across all treatments, the contribution of primary, secondary, and tertiary spikes to the total bean yield was 34, 28, and 26 percent in 1988, but 52, 32, and 17 percent in 1989. The contribution of quaternary spikes to total bean yield was 12 percent during 1988, but quaternary spikes did not produce any yield during 1989. Rainfall during 1989 was deficient at later stages of crop growth so that the secondary and tertiary spikes matured under moisture stress conditions. Comparing the mean effects across different doses, application of N as green leaves resulted in significantly higher bean yields than N supplied as urea. This advantage was more apparent in 1989,

Table 2. Yield of castor bean (kg/ha) as influenced by different sources and levels of nitrogen.

	1988					1989			
Treatment	PS	SS	TS	QS	Total	PS	SS	TS	Total
T_1	260	162	101	62	586	170	161	64	395
T_2	451	381	367	162	1360	536	328	156	1020
T_3	421	351	330	153	1255	442	217	140	790
T_4	389	324	347	141	1201	435	261	100	796
T_5	444	361	311	158	1273	510	305	128	943
T_6	466	391	374	153	1383	590	362	147	1099
T_7	350	361	325	156	1192	353	207	115	675
T_8	421	331	326	162	1240	430	281	149	847
T_9	439	340	317	168	1264	454	326	180	960
LSD (P = 0.05)	14.8	16.7	9.0	9.1	23.1	6.5	5.8	16.0	10.9

PS = Primary Spike; SS = Secondary Spike; TS = Tertiary Spike; QS = Quaternary Spike.

Table 3. Dry matter accumulation (g/m^2) of castor bean as influenced by different levels and sources of nitrogen.

	Days After Planting							
	1988				1989			
Treatment	45	75	105	Harvest	45	75	105	Harvest
T_1	13	29	106	225	5	55	96	122
T_2	41	92	216	440	11	101	175	224
T_3	38	84	180	388	12	86	154	200
T_4	29	76	167	315	10	85	148	195
T_5	35	85	175	350	11	92	157	206
T_6	38	89	184	379	13	100	169	217
T_7	28	73	164	298	9	77	138	183
T_8	34	76	167	325	10	89	146	193
T_9	36	81	194	372	11	90	153	206
LSD (P = 0.05)	2.7	3.5	4.3	5.4	1.2	3.2	3.6	3.2

when there was an extended deficit and uneven distribution of rainfall (Table 2).

The total dry matter (TDM) production followed a similar trend as the bean yields (Table 3). The TDM yields were significantly higher in the plots treated with green leaves as the source of N compared to N supplied by urea. During 1988, the highest TDM yields were recorded for T_2, followed by T_3. However, in 1989, plots that received green leaves at planting (T_2, T_6, and T_5) produced significantly higher TDM yields than those receiving urea (T_2, T_8, and T_9). The TDM yields were relatively lower in 1989 because of the rainfall deficit and the uneven distribution. Even during 1988, the plots that produced more DM (T_3 and T_9) recorded relatively lower bean yields at harvest since more N was utilized for vegetative growth, thereby leading to a lower harvest index. Based on the average values across different doses of N addition in the form of green leaves, incorporation at planting resulted in significantly higher TDM than incorporation at 45 DAP. The treatment effects were similar on individual components of the TDM, such as the stem, leaf and spikes, in both 1988 and 1989.

The leaf area index (LAI) was higher when 50 kg N/ha was added as green leaves (T_2), followed by T_6 (Table 4). Incorporation of green leaves at planting a all application rates caused higher LA compared to incorporation at 45 DA in both years.

The total N uptake at harvest followed a trend similar to that of the yield and yield components, with the highest mean N uptake in T_2 (63.8 kg N/ha), followed by T_6 (62.4 kg N/ha). The mean N uptake in the control plots was only 21.4 kg N/ha. However, N application to castor bean as green leaves caused markedly higher uptake, i.e., an average of more than 20 percent at different phenological stages, compared to N supplied as urea

As with other parameters, incorporation of green leaves at planting was significantly superior to 45 DAP.

Figure 2 shows mean bean yield and N uptake in 1988 and 1989 according to time of incorporation and N sources, averaged over application rate ($T_4+T_5+T_6$ compared to $T_7+T_8+T_9$). Values of T_2 and T_3 were also compared to determine the differences due to sources. Bean yields and N uptake followed the order green leaves > green leaves + urea > urea + green leaves > urea > control. The treatment effects were similar for TDM and LAI recorded at different phenological stages.

The data thus indicate that, for higher bean yields, TDM, LAI, and total N uptake, meeting the N requirement through incorporation of green leaves of *Leucaena leucocephala* was better than the application of urea. Secondly, incorporation of organic N at the time of planting was consistently better than application at 45 DAP, particularly under deficit rainfall conditions (Figure 3).

The relative N efficiency from green leaves and urea was compared in terms of apparent recovery (AR) calculated as follows:

$$AR = \frac{NF - NC}{NA} \times 100$$

where NF = N uptake on fertilized plots

NC = uptake on control plots

NA = amount of N applied

Green leaves as a source of N consistently showed higher AR compared with urea in both 1988 and 1989. During 1988, the AR was 98 in T_2 and 95 in T_6 compared with 88 in T_9 and 84 in T_3. The differences were more pronounced in 1989, where the AR values were 85, 89, and 57 in T_2, T_6, and T_3, respectively.

The data on N use efficiency (kg beans/kg N applied) and water use efficiency (kg beans/mm water used) of different treatments clearly showed the higher N and water efficiency with green leaves as the N source (Table 5). The differences between complete green leaves (T_2) and complete urea (T_3), and between T_6 and T_9, were more discernible during 1989, a drought year. In both years water use efficiency was significantly higher in the N applied plots com-

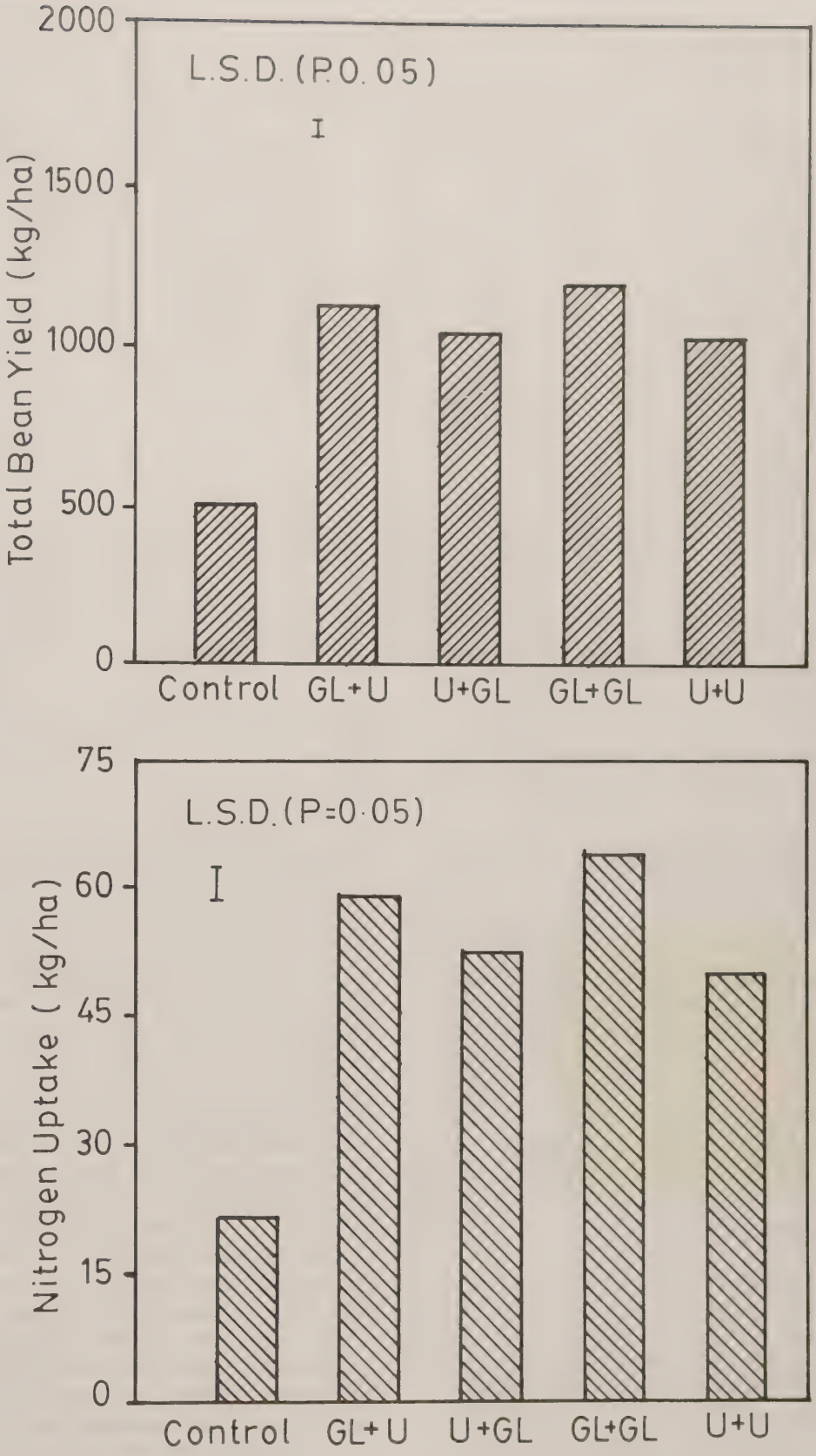

Figure 2. Bean yield (above) and Nitrogen uptake (below) in castor bean as influenced by the timing of incorporation of green leaves and urea (Mean of 1988 & 1989; GL:Green leaves; U:Urea).

Table 4. Leaf area index (cm^2/plant) of castor bean at different phenological stages as influenced by different sources and levels of nitrogen.

	Days After Planting							
	1988				1989			
Treatment	45	75	105	Harvest	45	75	105	Harvest
T_1	0.10	0.27	0.42	0.37	0.04	0.22	0.34	0.18
T_2	0.15	0.64	1.09	0.61	0.11	0.59	0.69	0.42
T_3	0.14	0.51	0.90	0.55	0.11	0.56	0.66	0.39
T_4	0.12	0.47	0.90	0.52	0.09	0.56	0.62	0.37
T_5	0.14	0.49	0.93	0.54	0.10	0.59	0.64	0.38
T_6	0.15	0.54	0.99	0.57	0.12	0.59	0.66	0.41
T_7	0.11	0.45	0.86	0.54	0.08	0.55	0.60	0.37
T_8	0.12	0.47	0.88	0.54	0.08	0.57	0.63	0.37
T_9	0.14	0.50	0.96	0.55	0.11	0.57	0.65	0.39
LSD (P = 0.05)	0.007	0.008	0.012	0.011	0.004	0.002	0.016	0.012

Table 5. Nitrogen and water use efficiencies in castor bean as influenced by green leaves and fertilizer N.

	Nitrogen Use Efficiency (kg bean/kg N applied)		Water Use Efficiency (kg bean/mm water)	
Treatment	1988	1989	1988	1989
T_1	—	—	1.14	1.25
T_2	15.5	12	2.65	2.89
T_3	13.3	7.9	2.44	2.50
T_4	12.3	8.0	2.34	2.53
T_5	13.8	10.9	2.48	2.99
T_6	13.7	14.1	2.70	3.49
T_7	12.1	5.6	2.32	2.14
T_8	13.0	9.0	2.42	2.69
T_9	13.6	11.3	2.46	3.04
LSD (P = 0.05)	0.56	1.85	0.25	0.31

pared with the control. Among the treatments, 37.5 kg N/ha as green leaves at planting followed by 12.5 kg at 45 DAP (T_6) recorded the highest WUE in both 1988 (2.69) and 1989 (3.49). Relatively higher WUE values were recorded during 1989, which was a deficit rainfall year.

Discussion

Although the advantages of green manuring and green leaf manuring have been well-demonstrated in irrigated agriculture, little conclusive data is available for rainfed or dryland conditions. This two-year field study clearly demonstrates the potential for replacing a substantial amount of the N fertilizer requirement with green leaves from *Leucaena leucocephala* grown as hedgerows on farm boundaries or as alleys in an agroforestry system. The advantages of an organic form of N have come out clearly under rainfed conditions, where soil water deficits are common during the growing season. Earlier studies have demonstrated the possible replacement of fertilizer N with green leaves of *Leucaena leucocephala* for production of sorghum and pearl millet (Narkhede et al., 1984; Subba Reddy et al., 1988). However, those experiments were conducted either during the post rainy season in deep black soils with assured moisture storage and availability or during the rainy season in alley cropping systems when the leaves from hedgerows were used as a mulch. An important aspect of this study has been the attempt to optimize the time of incorporation and substitution level.

The advantage of green leaves as a N source in the present study could also be attributed to its slow release compared with most kinds of chemical N fertilizers, where N can be readily lost through leaching or volatilization in these highly drained, light textured soils. This is apparent from the fact that basal application of green leaves resulted in higher yields and N uptake compared with application at 45 DAP. Nitrogen applied at planting as green leaves gradually becomes available in relation to plant development and increasing N demand. That is, the increased rate of mineralization of organic N tends to follow the increased demand for N by the growing crop. This leads to optimum N utilization as reflected in the higher bean yields from primary spikes when green leaves were applied at planting. Green leaves applied at 45 DAP would likely be less efficient in supplying the increasing amount of N to castor bean during the grand growth period (45-50 DAP onwards) because it would take time for the organic N to undergo mineralization and become available to the plant. In earlier studies we found that leaves and twigs of *Leucaena* take about 46 days under laboratory conditions to undergo 50 percent decomposition in these soils (Subba Reddy et al., 1988). This emphasizes the time that is necessary to facilitate mineralization and to ensure that enough inorganic N is available to the plant.

Another advantage of the green leaf material might be the increased moisture conservation in soil. Crops grown in plots where green leaves were applied consistently showed higher water use efficiency than in plots receiving urea. This was particularly apparent during the two drought periods in 1989, when the limited rainfall adversely affected the formation of primary spikes and the maturation of tertiary and quaternary spikes. Random measurements of the leaf water potential showed a consistent difference of about 0.5 MPa between the green leaf and urea plots during the two dry periods in 1989. There was a delay of wilting by 3 to 4 days in the green leaf plots, possibly because of the increased water conservation and slower rate of evaporation. Increased moisture storage due to better aggregate stability has been reported in light textured soils with the incorporation of organic residues (Unger, 1976; Rao and Singh, 1988). The higher N use efficiency of the green

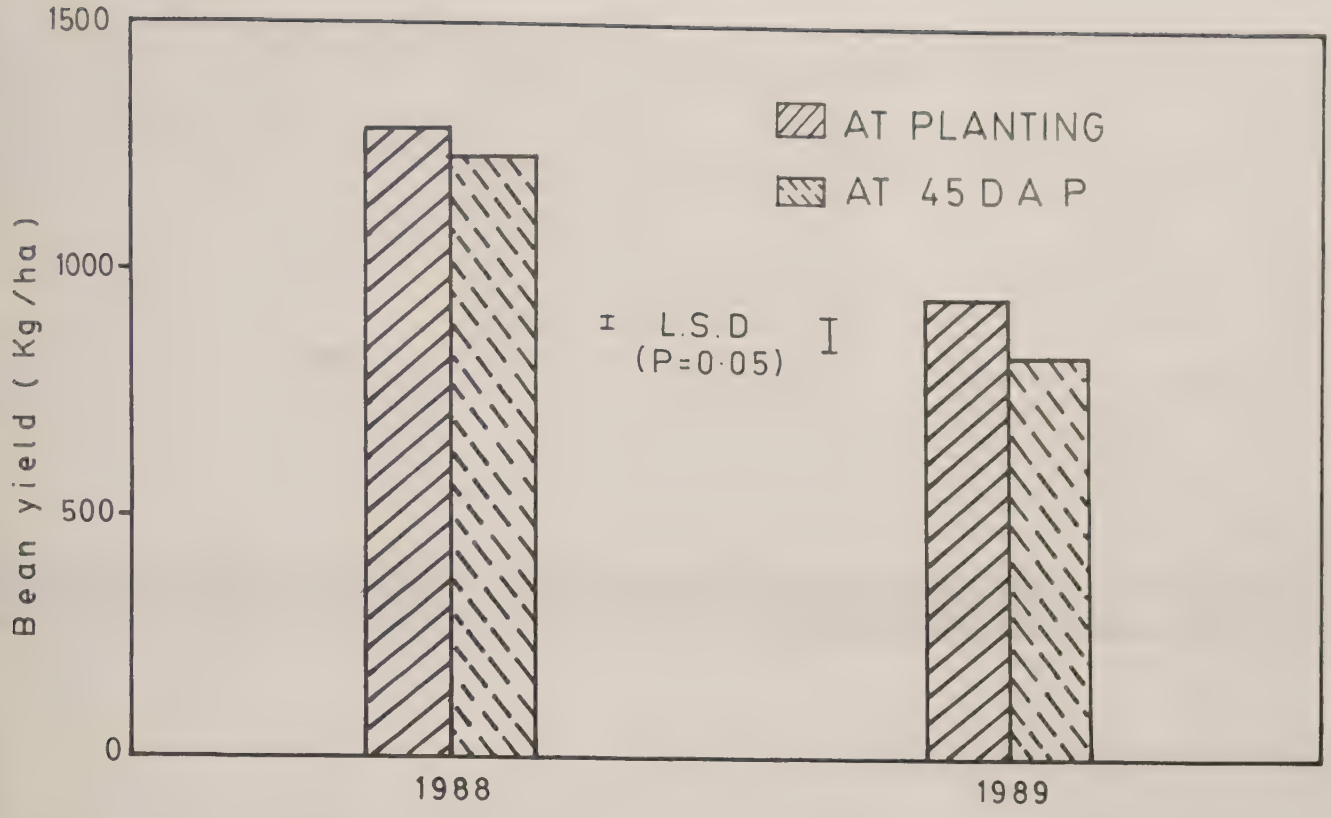

Figure 3. Mean effects of the time of incorporation of green leaves on the bean yield of castor bean during 1988 and 1989.

leaves is evident from the data on apparent recovery and nitrogen efficiency. This is particularly important during drought years, when farmers face the risk of low returns on the cost of N fertilizer due to suboptimal crop yields.

The increased N use efficiency from green leaves could also have been caused by the method of application. According to Hornick and Parr (1987), side dressing or band placement of organic amendments is agronomically advantageous since it places N in the immediate soil-root zone. It also minimizes leaching and volatilization losses and therefore is environmentally desirable. The fact that the highest bean yield came with 75 percent of the recommended N as green leaves at planting and the rest as urea at 45 DAP has significant agronomic implications for castor bean production because the green foliage of the hedgerows available from off-season growth can be utilized at the beginning of the rainy season. This could be an important strategy for using off-season rainfall for producing nitrogen rich biomass and recycling it during the rainy season. The potential for producing green leaf material in this amount from *Leucaena leucocephala* already has been successfully demonstrated in India (Narkhede and Ghugare, 1987).

Conclusions

This study clearly demonstrates the potential of utilizing green leaves of *Leucaena leucocephala* as a substitute for N fertilizer up to 75 percent of the recommended application rate for rainfed or dryland conditions. Nitrogen use efficiency of green leaves by castor bean was higher than from urea, particularly during deficit rainfall years.

These results indicate the need to determine the substitution or replacement levels of green leaf manuring for fertilizer N, the effect of split application, and the time required for mineralization of organic materials for other crops grown under dryland/rainfed systems. We especially need to know the nature of their interaction and how this affects plant nutrient availability and soil environment. Integrated nutrient management practices are needed to develop more productive, profitable, efficient, and sustainable farming systems and to reduce farmers' dependence on expensive purchased inputs, including chemical fertilizers.

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SPECIAL REPORT

Alternatives in animal husbandry

A conference that explored the many dimensions of the relationship between people and farm animals attracted about 250 scientists, research administrators, farmers, and members of animal welfare organizations to Witzenhausen, Germany, in July, 1991. The International Conference on Alternatives in Animal Husbandry, sponsored by the University of Kassel, drew participants from 16 countries and every continent.

The reason for holding the event, as explained by co-organizer Engelhard Boehncke, was that most conferences on organic and other alternative agricultural systems emphasize crop production. A meeting dedicated to the animal aspects of alternative agriculture was needed to insure that the subject got the attention it deserved.

Much of the conference was devoted to ways that farm animals could be allowed to carry out their normal behavior, such as rooting by pigs or dust bathing by poultry. Housing is especially relevant to this goal, for example, farrowing in huts on pasture and poultry production in aviaries rather than cages. Many speakers discussed the natural social structures of different livestock species and how agriculture can be made more compatible with them. Veterinary, nutritional, and breeding considerations also were important themes, e.g., the interaction between production systems and animal health, the health aspects of different feeding regimes, and preservation of endangered traditional breeds. Other speakers talked about the governmental regulation of animal production, ethical issues, and the special problems posed by genetic engineering of livestock.

The sessions were complemented by trips to nearby farms that use innovative methods in dairy, beef, poultry, and swine production. All these farms at least partially reflect the conference theme of producing livestock in a manner suited to the species' needs. However, in discussion meetings following the visits, many participants were not satisfied with what they saw. For example, although raising sows on pasture gives them more room to move around, on this farm the sows had nose rings to keep them from digging up the pasture. Many people felt that interfering with the sows' instinctual need to root outweighed the benefit of farrowing on pasture. Instead, they favored improved indoor housing, such as a system being studied in Switzerland in which sows and fattening pigs are raised together.

Another field trip was to the experimental farm of the University of Kassel, where field crops and vegetables are raised organically, with dairy bull calves fattened with feeds raised on the farm. After the conference, many participants also saw a nearby composting facility that treats household organic wastes from 50,000 people. Originally established as a pilot project under the auspices of the university, it now is a privately operated enterprise, selling about 6,000 tons of compost annually for home gardening and landscaping.

Together, the papers, poster sessions, discussions, and field trips offered a good overview of a wide range of farm animal welfare issues, with a particular orientation toward the ideas of alternative agriculture.

The proceedings volume (English, 365 pp., softbound) is available for $30, including air postage. Order from: Dipl. Ing. Inka Boehncke, Gesamthochschule Kassel, Fachbereich Landwirtschaft, Nordbahnhofstrasse 1a, D-3430 Witzenhausen, Germany. Include check or international money order payable to Gesamthochschule Kassel.

Runoff impoundment for supplemental irrigation: An economic assessment

F. G. Scrimgeour and G. W. Frasier

Abstract. *Water harvesting technologies capture surface water runoff and recycle it for productive use. Despite the long history of water harvesting and the renewed interest in many places in the world, the technology has not been widely adopted in the United States, in part because of a lack of understanding of its economic benefits. We developed a simulation model for the economic evaluation of water harvesting systems that combines agronomic, engineering, and economic factors and daily meteorological data. The simulation model was used to investigate the economic feasibility of using a water-harvesting, supplemental irrigation system for grain sorghum production over a 44-year period at two locations in Texas. Water harvesting combined with supplemental irrigation was most successful where the precipitation is the highest. However, the net benefits were extremely variable from year to year. The modeled technique could not take advantage of the potential additional water in the wet years and did not harvest sufficient water in dry years to make water harvesting more economically attractive than conventional dryland farming. This does not mean that runoff farming cannot be of economic benefit, depending on local conditions. Widespread adoption of the technology is constrained by the limited profit potential, the variability of the profits, and the knowledge required to use the technology successfully. The simulation model was a useful and simple tool for dealing with the complexity of the issues.*

Key words: water-harvesting, runoff-farming, drought, dryland-farming, model, simulation

Introduction

In many places irrigated agriculture is no longer economically feasible because of declining ground water levels. The reduced ground water supply has increased the interest in other potential water sources and various water conservation practices. These practices include conservation tillage, conservation bench terraces, fallowing, furrow disking, limited irrigation dryland system, skip row production, and reservoir storage with supplemental irrigation (water harvesting). They vary in their cost, effectiveness, and practicality. Conservation tillage, fallowing, furrow disking, and skip row production are relatively cheap. However, conservation tillage requires a high level of chemical use for weed control; furrow dikes must be rebuilt after each cultivation and may cause water logging in wet seasons; and fallowing and skip row production take land out of a yearly production cycle. Conservation bench terraces and reservoir storage for excess surface runoff with supplemental irrigation are more costly investments. With all techniques, benefits will vary because of fluctuations in precipitation characteristics, such as storm size and annual amount, and in economic conditions.

Krishna et al. (1987) showed that in east Texas, based on annual averages, a runoff farming system with a water impoundment reservoir for supplemental irrigation was promising for increasing and stabilizing crop yields, gross income, and profits. The system is described as: "The collection of surface runoff from cropped land into on-farm impoundments and subsequent application of this water as supplemental irrigation to crops on the same watershed during periods of crop water stress."

Economic feasibility requires that a cropping system be able to provide an adequate return on a yearly basis. The performance of any runoff farming system depends on the timing and quantity of individual precipitation events. For economic sustainability, the stochastic nature of rainfall and evaporative demand make it important to consider the operation of the farming system, within any one year and from year to year. This paper evaluates the yearly economic potential of using a runoff farming, supplemental irrigation system for growing sorghum (*Sorghum bicolor*) at two locations, Bushland and Temple, Texas. This analysis is accomplished through simulation modeling.

Simulation adds practical plausibility to investment analysis and is useful for exploring possible investment strategies and their uncertain consequences. This exploration of the stochastic dependence resulting from the joint dependence of some variables is a great advantage. It is particularly useful where investments are complex and the distributions are not normal (Anderson et al., 1977).

There are many farming systems that potentially are suitable for a given area. This analysis considers one approach to illustrate how yearly climatic conditions can affect yearly profit or loss and is not meant to promote or discourage any type of farming operation. Scrimgeour (1989) considers the use of four different water harvesting technologies at two sites in Texas.

F. G. Scrimgeour is Lecturer in Economics, University of Waikato, Private Bag 3105, Hamilton, New Zealand. G. W. Frasier is Research Hydraulic Engineer, USDA-ARS, Rangeland Resource Research Unit, 1701 Center, Fort Collins, CO 80526.

Model and site description

Model

The simulation model used is based on the conceptual design of an economic evaluation of water harvesting systems developed by Scrimgeour (1989). The model incorporates all available hydrological, biological, and economic information necessary for the calculation of costs, benefits, and risks of runoff farming systems under different environmental conditions, such as precipitation, and economic conditions, such as crop price. This approach accounts for the joint dependence of the stochastic variables.

Input data for the model include daily rainfall data, monthly pan evaporation, costs of production, and grain prices. The model consists of five components: catchment (runoff), impoundment (water storage), soil, crop, and economic. The model simulates production and generates a range of outcomes (maximums, minimums, averages, and standard deviations) and shows how yields, costs, and profits vary by years (seasons) for a given farming system design and decision rule. The model simulates final outcomes and predicts input supply and demand in intermediate time periods. Some of the important components of the biophysical system that are calculated for each time period are runoff, drainage, overflow, irrigation water applied, and crop water consumption.

The submodel components are specified by the following equations:

$RO_d = 0.4\ (RF_d - 6.35)$ (1)

where RO_d is the daily runoff (mm) and RF_d is the daily rainfall (mm);

$D_d = D_{d-1} + ADD_d - S_d - RE_d - O_d - IA_d$(2)

where D is the volume of water in the reservoir, ADD is the additions to the reservoir, S is the seepage losses from the reservoir, RE is the evaporative loss from the reservoir, O is the overflow loss from the storage, and IA is the quantity of irrigation water applied (all in m^3), and d is the time (days);

$ADD_d = RO_d * CA$ (2a)

where CA is the water collection area (ha);

$S_d = .006\ (WST_d)$, (2b)

where WST is the wetted surface area of the reservoir (m^2);

$RE_d = 0.618\ (PE_d * RA)$, (2c)

where PE is the pan evaporation (mm) and RA is the reservoir area (ha);

$PAW_s = PAW_{s-1} + RF_s + I_s - DD_s - ET_s$ (3)

where PAW is the plant available water, DD is the water lost by deep drainage, ET is the water lost by evapotranspiration, and I is the depth of irrigation water applied (all in mm), and s is the growing season;

$Ecum = 3.05\ (DSR)^{.5}$ (3a)

where Ecum is the cumulative evaporation (mm) and DSR is the number of days since the last rain;

$$E_d = Ecum_d - Ecum_{d-1} \quad (3b)$$

$$RF_d = \sum_{d=1}^{n} RF_d \quad (3c)$$

where n is the length of the growing season (days).

$$I_s = \sum_{d=1}^{n} 0.1\ (IA_d / AC) \quad (3d)$$

where AC is the irrigated area (hectares);

$$DD_s = \sum_{d=1}^{n} DD_d \quad (3e)$$

$$ET_s = \sum_{d=1}^{n} E_d \quad (3f)$$

$Yld = 0\ (PAW_s < 152)$ (4)

$Yld = 15.44\ (Paw_s - 152)$, $(152 < PAW_s < 635)$ (4a)

$Yld = 4.41\ (Paw_s - 635) + 7448\ (635 < PAW_s)$ (4b)

where Yld is the crop yield (kg/ha). There are other yield subroutines from other models such as EPIC (Williams et al., 1988) and IBSNAT (Thornton and Dent, 1987) which may be applicable.

$Profit = (P * Yld) - VC - FC$, (5)

where P is the grain price ($/kg), VC are the variable costs, and FC are the fixed costs.

Sites

Runoff farming systems with supplemental irrigation were modeled for two sites, Bushland and Temple, Texas. Both locations are USDA-ARS research laboratories with detailed soil, climate, and crop production data. The results are compared to an analysis of a conventional dryland farming system at both locations.

The Bushland, Texas, climate is classified as semiarid with high evaporation rates (1900 mm annually from free water surfaces) and low average annual rainfall. Annual rainfall averages 470 mm but is highly variable in both amount per year and per storm. During the study period (1941-1985), annual precipitation ranged from 240 mm to 830 mm. Seventy-five percent of the rainfall normally occurs during the six-month growing season, April through September. Temperatures range from a January average minimum of -5 C to a July average maximum of 33 C (USDA-ARS, undated).

Temple, Texas, has a wetter climate than Bushland. The annual rainfall average is 840 mm, ranging from 340 mm to 1270 mm during the study period. Approximately 55 percent of the rain falls during the six months from April through September. Free water surface evaporation is 1470 mm annually. Temperatures range from a February average minimum of 5 C to an August average maximum of 36 C (Bloodgood et al., 1954).

The simulated farm layout consisted of an 80 hectare area (Figure 1). Runoff water was collected from the entire 80 hectare area and stored in an impoundment reservoir for later application in two supplemental irrigations to a 53 hectare crop area within the farm. The remaining 27 hectare area was primarily used as a water contributing area planted to a dryland grain sorghum that would provide some grain production in the wetter years.

Based on studies by Frasier (1975), the total annual water yield (runoff) from the area was estimated as 40 percent of any daily rainfall in excess of a threshold of 6.4 mm. Seepage losses from the impoundment were assumed to be 6 mm per day of wetted perimeter (Laing, 1975). Evaporation losses from the storage reservoir, reduced by the use of evaporation suppressants (Cooley, 1975), were assumed to be 40 percent of open

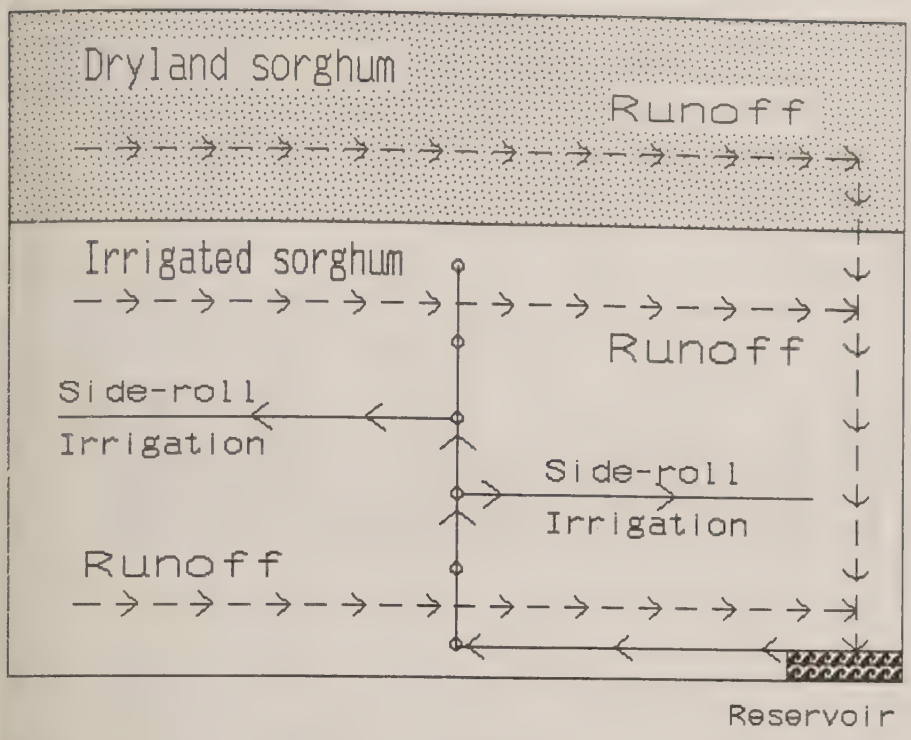

Figure 1. Sketch of simulated farm layout.

pan evaporation.

The optimal reservoir size is determined by the tradeoff between the added benefit from a larger storage versus the cost of the additional storage. Following Krishna et al. (1987), the pond size used was sufficient to store, at any single time, a volume of water equivalent to a depth of 58 mm over the irrigated area. The collected water, up to a total of 116 mm, was applied in two irrigations (two full storages) to the irrigated area at a total cost of $57/ha. The cost of irrigation includes the total interest and depreciation for the year. Any collected water in excess of 116 mm but less than 175 mm (three storages) was applied in a third irrigation at a cost of $25/ha. Where a third application of water was made, there was no interest or depreciation charge.

Collected water in excess of 175 mm per irrigated hectare was lost as overflow from the storage. The soil profile was assumed to be saturated when a total of 254 mm of water was accumulated by irrigation and/or rainfall. Excess infiltrated water was lost through deep drainage. Evaporation from the soil during the fallow period was assumed to vary as the square root of the number of days after rain, with evaporation on the first day equal to 3 mm. This approximates the results of Ritchie (1972). The water necessary to establish a crop was assumed to be 152 mm. Each additional mm of available water was assumed to increase the crop yield by 15.4 kg per hectare (Stewart et al., 1983) up to 7448 kg per hectare with 635 mm of plant available water. Beyond this, the addition of each mm of water was assumed to increase the yield by 4.4 kg per hectare.

The growing season was assumed to be March to June in Temple, Texas, and from June to September at Bushland, Texas. Despite the climatic differences at the two sites, it is assumed that the differences in soil, temperature, and other environmental factors do not alter the relationship between plant available water and crop yield.

Variable costs of crop production (cultivation, seed, fertilizer, labor, weed and pest management, and harvest expenses) were assumed to be $175 per hectare for the dryland sorghum and $195 for the supplementally irrigated sorghum (Texas Agricultural Extension Service, 1988). The capital costs for constructing the water harvesting system were assumed to be $26,215 for the impoundment and $20,000 for the irrigation equipment. This is equivalent to an annual cost of $96/ha for the 53 irrigated hectares using 9 percent interest, a 20-year life for the irrigation system, and an infinite life for the water impoundment facility, with annual maintenance charges of $520. Sorghum price was assumed to be $0.10 per kilogram.

Table 1. Comparison of model results with published data.

		Model	Published
Runoff (% of rainfall)	Minimum	0	22 [a]
	Average	13	–
	Maximum	40	32
	Standard deviation	11	–
Fallow Efficiency	Minimum	0	12 [b]
	Average	19	24
	Maximum	39	43
	Standard deviation	10	7
Grain yield (kg/ha)	Minimum	0	880 [c]
	Average	1640	1710
	Maxium	4710	2450
	Standard deviation	1260	425

[a] Frasier, 1975
[b] Steiner, 1989
[c] Lansford et al., 1986.

Model validation and procedures

The model results were validated by comparison of computed catchment runoff efficiencies and the fallow efficiency and yields to published results from other studies (Table 1). The catchment runoff efficiencies were derived from experimental watersheds in Arizona (Frasier, 1975). The fallow efficiency and yield results were from studies of a fallow farming system at Bushland, Texas. Fallow efficiency is defined as the percentage of fallow period rainfall stored in the soil profile at the end of the fallow period. The results reported by Steiner (1989) were based on the effects of different residue levels on soil water evaporation. The results of Lansford et al. (1986) on grain yields are based on the averages for groups of counties in Texas. There was a reasonable similarity between the model results and the published data.

Results and discussion

At both locations over the 44-year simulation period, there was an average increase in available plant water of approximately 30 percent (Table 2); but the amount of the increased water varied considerably from year to year (Figure 2). In wet seasons, water overflowed from the impoundments and was lost from any beneficial use. In dry seasons there was insufficient rainfall to fill the impoundments, limiting the amount of water available for supplemental irrigation.

At Bushland the simulated grain yields with supplemental irrigation ranged from zero to more than 7400 kg/ha. At Temple with supplemental irrigation the range was from 1240 kg/ha to more than 8400 kg/ha (Figure 3). The supplemental irrigation did not significantly reduce the risk of total crop failure compared to a conventional dryland farming system. However, without water harvesting in 2 of the 44 years, yields were less than 1120 kg/ha, but with water harvesting the minimum yield in any year was 1120 kg/ha. At Bushland the supplemental irrigation increased yields by more than 1120 kg/ha in 23 of the 44 years and at Temple in 39 of the 44 years.

Table 2. Simulated plant available water

	Bushland		Temple	
	Mean	(Range)	Mean	(Range)
	(mm)		(mm)	
Water stored in profile	58	(0-150)	166	(7-254)
Rainfall (growing season)	199	(81-374)	249	(101-487)
Plant available water (no irrigation)	257	(119-258)	415	(182-679)
Supplemental irrigation	83	(0-175)	124	(41-175)
Plant available water (w/irrigation)	340	(133-633)	539	(233-854)

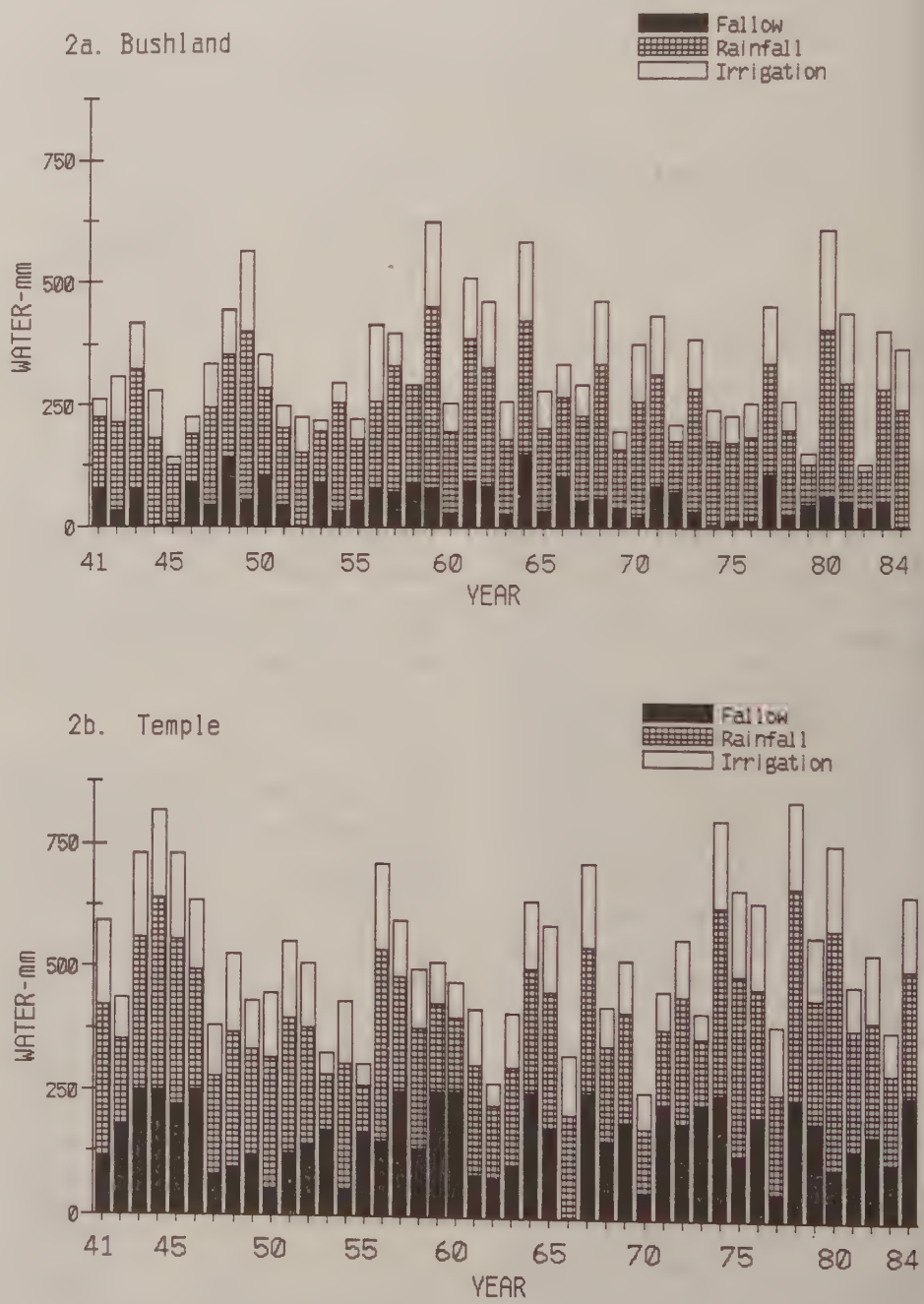

Figure 2. Simulated yearly quantities of water available for plant growth from fallow carryover, rainfall during the growing season, and supplemental irrigation for the 44-year study period at Bushland (2a) and Temple (2b), Texas.

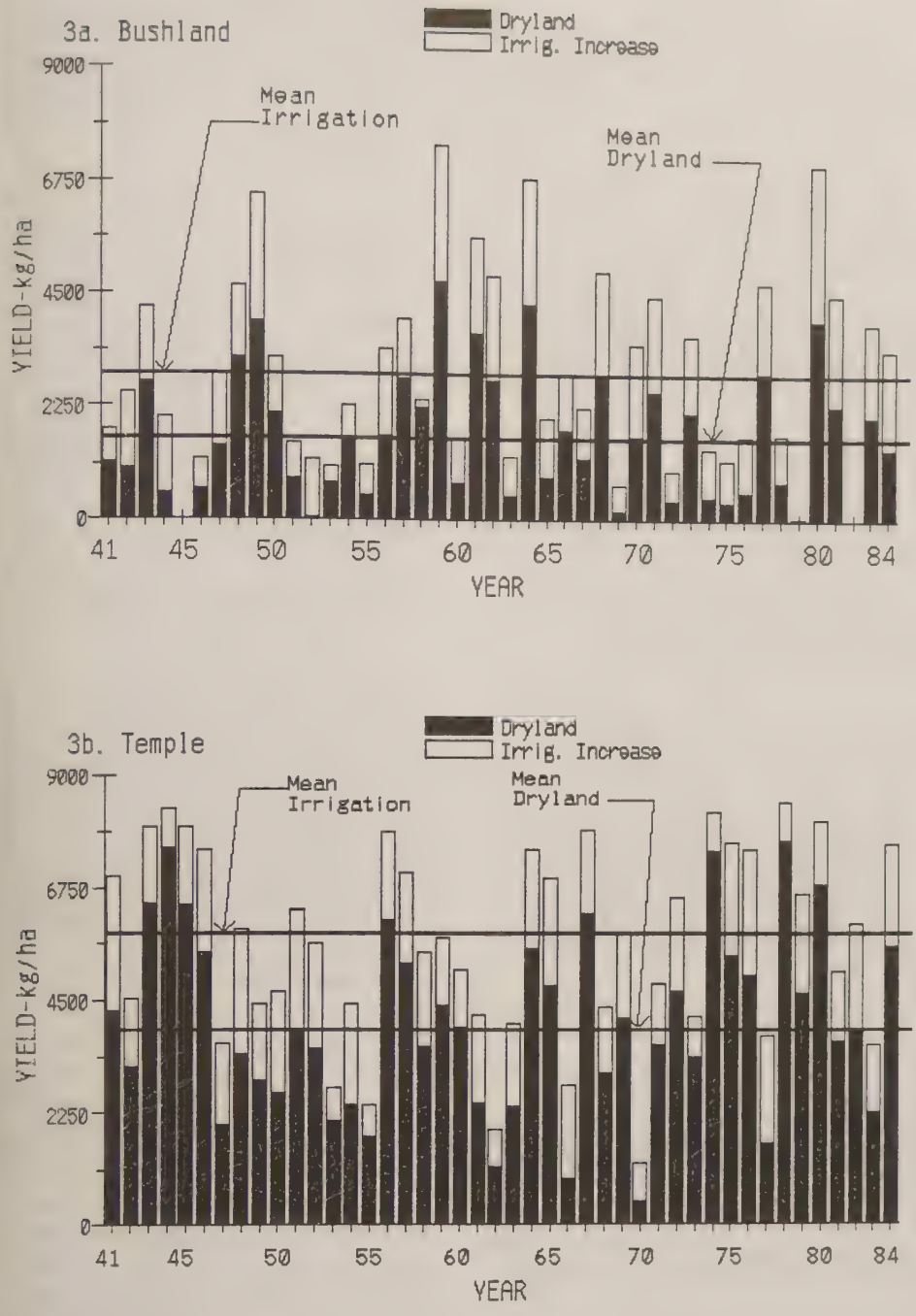

Figure 3. Simulated yearly yield of grain sorghum grown under dryland and supplemental irrigation for the 44-year study period at Bushland (3a) and Temple (3b), Texas.

Table 3. Simulated profit

	Bushland		Temple	
	Mean	(Range)	Mean	(Range)
	($ /ha)			
Annual Profit:				
Without supplemental irrigation	−15	(−178, 292)	225	(−131, 585)
With supplemental irrigation	−45	(−285, 339)	227	(−188, 505)

The increases in yield do not translate directly into increased profitability because of the fixed costs of the investment and the additional variable costs of more fertilizer and seed applied to the irrigated crop. The average annual cost per hectare of supplemental irrigation is $1.86 per mm at Bushland and $1.32 per mm at Temple. At Temple, the water harvesting investment resulted in no significant change in average profitability, with an average annual net benefit from the investment of $2 per hectare. At Bushland, the water harvesting, supplemental irrigation system investment had an annual net loss of over $30 per hectare (Table 3). The net benefit varied greatly from year to year. In some years the water harvesting resulted in a net loss compared with the absence of the investment (Figure 4).

There is more variation in the net benefit than there is in the yield or the rainfall. This variation is measured by the coefficient of variation (standard deviation/mean) (Table 4). These results indicate that water harvesting may reduce the probability of crop failure, but it does not reduce the variability in profitability. The analysis did show a sensitivity to grain prices. A $0.10/kg increase in grain price resulted in a significant increase in profit at both test sites with and without the supplemental irrigation system (Table 5). A similar analysis was conducted using a playa lake or other existing water storage facility rather than a new reservoir. If water storage construction costs could be reduced to 25 percent of the cost of constructing a conventional reservoir, the annual profit improves by approximately $5 per irrigated hectare (Table 6).

Conclusions

For the criteria used, supplemental irrigation from a water harvesting system did not increase the profitability of sorghum grain production at two locations in Texas. Water harvesting combined with supplemental irrigation was most successful in the location where the volume of water harvested was greater, i.e., where precipitation was higher. However, the net benefits were extremely

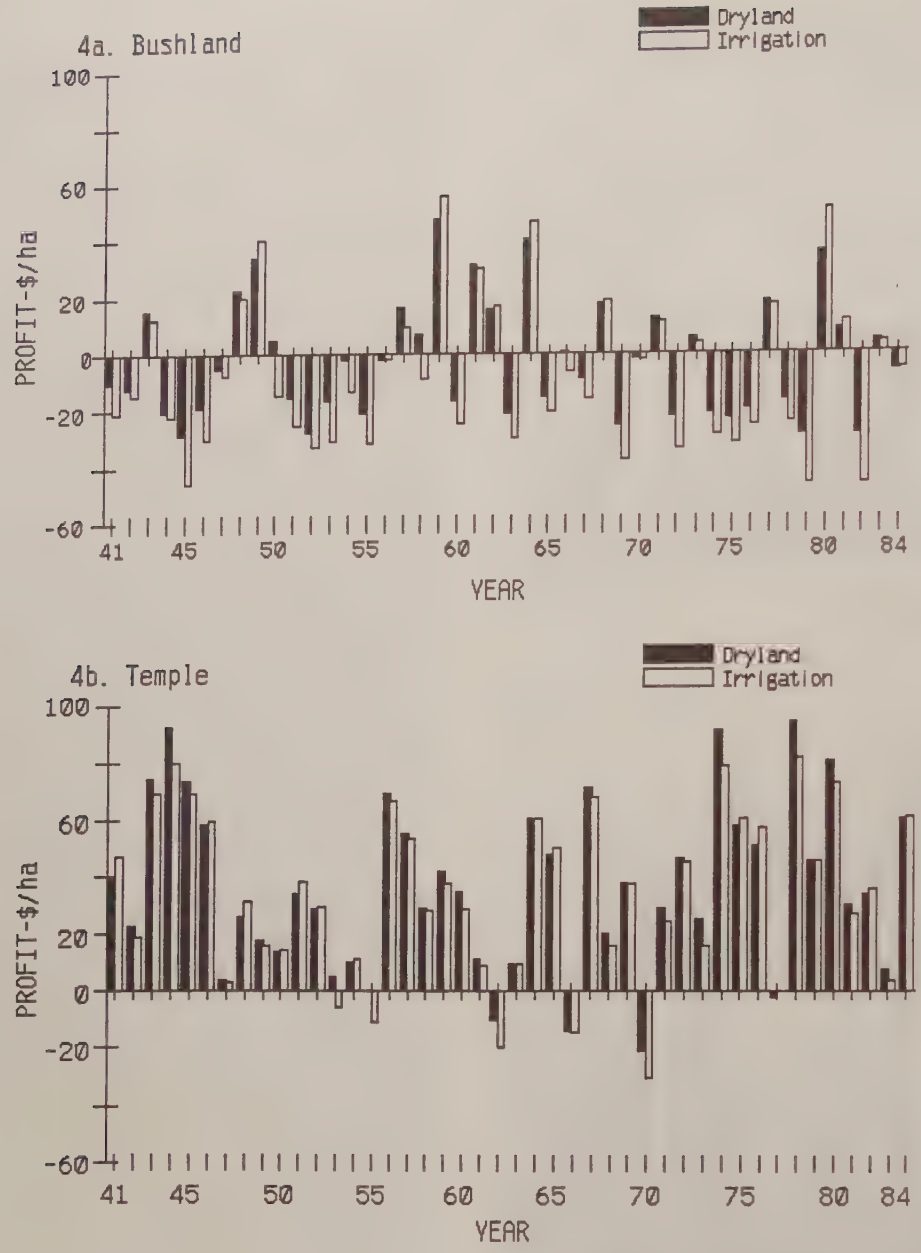

Figure 4. Simulated yearly net profit (loss) of growing grain sorghum under dryland and supplemental irrigation for the 44-year study period at Bushland (4a) and Temple (4b), Texas.

Table 4. Variation in results

	Bushland			Temple		
	Mean	sd	cv	Mean	sd	cv
Rainfall: (mm)						
Annual	469	117	.25	835	194	.23
Growing season	199	68	.34	249	85	.34
Plant Available Water: (mm)						
Without irrigation	257	85	.33	415	119	.29
With irrigation	340	125	.37	539	152	.28
Yield: (kg/ha)						
Without irrigation	1643	1291	.79	4034	1807	.45
With irrigation	2911	1916	.66	5655	1908	.34
Profit: ($/ha)						
Without irrigation	−15	126	8	225	180	.81
With irrigation	−45	161	4	227	209	.92

Table 5. Profit as a function of grain price

	Sorghum Prices	
	$0.10/kg	$0.20/kg
	($/ha)	($/ha)
Bushland:		
Without irrigation	−15	148
With irrigation	−45	200
Temple		
Without irrigation	225	626
With irrigation	227	733

Table 6. Annual profits as a function of reservoir costs

	Natural Reservoir	Constructed Reservoir
	($/ha)	($/ha)
Bushland:		
With irrigation	−37	−45
Temple		
With irrigation	235	227

variable from year to year. The modeled water harvesting technique was not able to take advantage of the potential additional water in the wet years and did not harvest sufficient water in dry years to make water harvesting more economically attractive than conventional dryland farming. For the water harvesting system to be more profitable on a yearly basis than dryland sorghum farming, there must be a yield increase of about 1600 kg/ha or more with the supplemental irrigation system. To achieve this yield increase, the runoff farming system must consistently harvest sufficient water to provide an additional 110 mm of supplemental irrigation to the irrigated area. This does not mean that there are not situations or conditions where runoff farming would be of economic benefit. The model did show that the net profit benefit was significantly increased with an increase in grain prices.

Water harvesting is a complex technology that has benefits in some locations. Each situation needs to be evaluated on its own merit and conditions. Widespread adoption of the technology is constrained by the limited profit potential, the variability of the profits, and the knowledge required to successfully use the technology. The simulation model used in this evaluation was found to be a useful and simple tool for dealing with the complexity of the issues.

Acknowledgments. The authors acknowledge with thanks Dr. J. L. Steiner, USDA-ARS, Soil and Water Conservation Laboratory, Bushland, Texas, and Dr. C. W. Richardson, USDA-ARS, Grassland Soil and Water Research Laboratory, Temple, Texas, for providing precipitation and evaporation data.

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UPCOMING EVENTS

May 4-5. An **Amish Study Tour** will be held in Berlin, Ohio. Contact Ed Martsolf/Arlene Musselman, A Whole New Approach; (501) 889-2915.

May 17-20. Fourth North American Symposium on Society and Resources Management will be held in Madison, Wisconsin. Contact Donald R. Field, School of Natural Resources, 1450 Linden Drive, Madison, WI 53706.

June 4-7. Diversity in Food, Agriculture, Nutrition and Environment will be held at the Kellogg Center, Michigan State University, East Lansing, Michigan. Sponsors are the Association for the Study of Food and Society and the Agriculture, Food, and Human Values Society. Contact Lawrence Busch, Program Chair, Department of Sociology, MSU, East Lansing, MI 48824-1111.

June 22-26. A Theology for Coming Home, sponsored by American Baptist Churches, USA Board of National Ministries, American Baptist Churches of the Central Region, and The Land Institute, will be held in Salina, Kansas. Contact Dr. A. David Stewart, 1801 Anderson, Manhattan, KS 66502; (913) 539-3538.

July 14-22. International Crop Science Congress will be held at Iowa State University in Ames, Iowa. Contact Brian Meyer, ISU Ag Information, (515) 294-0706; or Steve Jones, ISU News Service, (515) 294-4778.

July 30-August 1. Participatory On-Farm Research and Education for Agricultural Sustainability, sponsored by Agricultural Research Institute, University of Illinois College of Agriculture, American Society of Agronomy, USDA-EPA, and LISA-ACE Program, will be held in Champaign, Illinois. Contact Dr. John M. Gerber, UI Agricultural Experiment Station, 211 Mumford Hall, 1301 West Gregory Drive, Urbana, IL 61801; (217) 244-4232.

August 9-12. Resource Management in a Dynamic World, the Soil and Water Conservation Society's Annual Meeting, will be held in Baltimore, Maryland. Contact Tony Vrana, SWCS, 7515 Northeast Ankeny Road, Ankeny, IA 50021-9764; (515) 289-2331.

August 11-16. Rural Society in the Changing World Order, the 8th World Congress for Rural Sociology, will be held at Pennsylvania State University, followed on **August 16-19** by **Rurality and the Global Environment,** the 55th Annual Meeting of the Rural Sociological Society. Contact World Congress/RSS, Penn State, 306 Agricultural Administration Building, University Park, PA 16802; (814) 865-8301.

August 14-16. 18th Annual Conference, Natural Organic Farmers Association, will be held at Hampshire College, Amherst, Massachusetts. Contact Julie Rawson, 411 Sheldon Road, Barre, MA 01005; (508) 355-2853.

August 19-22. Industrial and Third World Environmental Assessment: The Urgent Transition to Sustainability, the 12th Annual Meeting of the International Association for Impact Assessment, will be held at the World Bank, Washington, DC. Contact Maurice E. Voland, IAIA, P.O. Box 70, Belhaven, NC; (919) 964-2340.

November 16-21. Organic Agriculture, A Key to a Sound Development and a Sustainable Environment, a scientific conference of the International Federation of Organic Agriculture Movements, will be held in Sao Paulo, Brazil. Contact SOMA Rel. e Com. Ltda, Rua Atlantica, 81, 10440, Sao Paulo, SP, Brazil.

COMMENTARY

Energetics and ecosystem integrity: The defining principles of sustainable agriculture

Timothy E. Crews, Charles L. Mohler, and Alison G. Power

Abstract. *In this paper, we criticize recent definitions of sustainable agriculture as being overly based on short-term economic criteria, rather than long-term ecological criteria. A concise definition of sustainable agriculture is put forth, premised on the assumption that the ecological parameters of energetics and ecosystem integrity ultimately determine the long-term viability of farming systems. We share with others the view that, in designing sustainable farming systems, a broad array of social and economic factors should be taken into consideration. We believe, however, that these factors are not intrinsic to a sustainable agriculture, but rather separate, desirable goals.*

Key words: sustainable agriculture, energy, ecological, social, economic, sustainability

In considering the various systems of agriculture which so far have been devised, it will be interesting to see how far Nature's principles have been adopted, whether they have ever been improved upon, and what happens when they are disregarded.

--Sir Albert Howard (1943, p. 4)

Many current definitions or criteria of sustainable agriculture arose from an urgent need to make farming more environmentally sound, to revitalize rural communities, and to improve the financial standing of farmers. Although they may not say so explicitly, these definitions often imply that, if these ends were met, today's agriculture could be considered "sustainable." We agree that many changes farmers are undertaking today are making our agriculture more sustainable; these changes should be supported. However, we argue that moving toward sustainability and being sustainable should not be considered the same.

We believe that, by equally weighing all ecological, sociological, and economic characteristics of what might comprise a sustainable agriculture, many authors have blurred the relationships among these components. This has resulted in excessively broad definitions that fail to provide an unambiguous guide to future action. We argue here that the profitability of sustainable agricultural systems is constrained by the social structure of agriculture but that sustainability itself is constrained solely by the ecological conditions of agriculture.

Ecological sustainability

The original and probably the most commonly discussed focus of the movement in sustainable agriculture is the need to make agriculture more environmentally sound. Many authors cit ground water contamination, down stream eutrophication, pesticide poison ings, soil erosion, the selection of resist ant crop pests, and other environmenta concerns as issues that need to be ad dressed in the development of sustain able agricultural systems (Lockeretz 1988; Keeney, 1989; Carter, 1989; Stin ner and House, 1989; Madden, 199(Francis and Youngberg, 1990). In addi tion, the need for farming practices an food distribution systems that conserv energy is often mentioned, since increas ing costs of fossil fuels and ultimatel the depletion of fossil fuel resources ar anticipated. We believe that these con cerns not only are valid, but that enoug is known about basic ecosystem pattern and processes to state them in a muc more rigorous and meaningful way (Ta ble 1).

Energetics

Much of the success of modern agr culture is due to inexpensive fossil fuel In this century, fossil fuels have bee used to overcome abiotic and biotic lim tations on crop productivity, includin weed competition, insect damage, def ciencies of nutrients and water, plant di eases, and shortages of human labor. Th principal uses of energy in agricultu are for the manufacture of fertilizers an pesticides and the operation of farm m chinery and irrigation systems (Piment et al., 1989). Although admittedly or can only speculate about future energ

Timothy E. Crews is a Graduate Student, Charles L. Mohler is Research Associate, and Alison G. Power is Associate Professor, Section of Ecology and Systematics, Cornell University, Ithaca, NY 14853-2701.

Table 1 Ecological constraints on sustainable agriculture

General Parameters	Farming Practices Most Affected
1. A sustainable agriculture uses only renewable energy sources. The energy yield from farming must be greater than the energy used in the production process.	fertilization pesticide use mechanized tillage, harvesting, etc. irrigation
2. A sustainable agriculture does not degrade the integrity of the ecosystem of which it is a part.	
a. Soil fertility is maintained	one-time usage of nutrients cropping patterns highly erosive tillage practices
b. Water resources are not depleted	irrigation
c. Human health is not jeopardized	pesticide use fertilization
d. Species diversity is maintained	extensive monocropping practices linked to high rates of greenhouse gas production use of bioengineered organisms fertilizer and pesticide use

availability, we think it is imperative when discussing sustainable agriculture. Not only does energy availability directly affect farm production as described above, but in many cases it also determines what is sustainable from the perspective of ecosystem integrity. For example, if energy were not considered a limiting factor, a "sustainable" agriculture conceivably could rely on water pumped thousands of miles from its source, or soil erosion could be countered by dredging sediments from reservoirs and transporting topsoil back up to the agricultural watersheds from which they originated. Although such ecosystem-level manipulations may seem absurd, there is no reason necessarily to discount such measures as not sustainable, if energy is not limiting.

The relevance of fossil energy use to discussions of the sustainability of agricultural systems depends on several assumptions. Our assumptions are the following:

- fossil energy is finite, and the most useful resources are being rapidly depleted
- dependence on nuclear energy is undesirable
- concepts of sustainability in agriculture should not be based on faith in the future development of vast sources of inexpensive energy from unproven technologies.

If these assumptions are made, then the sustainability of an agricultural system depends on the farmer's capacity to capture more solar energy in the harvest than he or she uses to plow, irrigate, and perform other energy requiring practices involved in growing the crop. Another way of stating this is to ask, if the fossil energy pipeline stopped today, could a given agricultural system continue indefinitely? For this to happen, a significant net solar energy capture has to be made by the farming system as a whole.

Other workers may base their ideas of sustainable agriculture on the assumption that large amounts of inexpensive energy may become available from nuclear power or other sources. Such ideas may be legitimate, but coherent discussion of the issues is impossible unless the sources of energy for agriculture are identified explicitly.

Ecosystem integrity

In addition to the thermodynamic constraint described above, we have identified four additional conditions that must be met if farm productivity is to be maintained over the long term: maintenance of soil fertility; preservation of water supplies; protection of human health; and conservation of species diversity.

In a sustainable agriculture, the fertility of the soil is not mined. Soil fertility should not be degraded through gradual reduction in the level of soil organic matter or through the much more rapid process of soil erosion. To maintain soil fertility, not only must soil erosion be held to the local rate of soil replacement, but nutrients that leave the farm in leaching, runoff, and food must be balanced by nutrients that are made available through weathering of primary and secondary minerals, atmospheric deposition, and biological nitrogen fixation. Soil fertility in one place could be supplemented with nutrients gathered or fixed at another location so long as the energy constraint put forth is not violated.

In a sustainable agriculture, water resources are not depleted. For an agricultural system to be sustainable, fossil water cannot be pumped from an aquifer for irrigation at a rate that exceeds the rate of replenishment. Water conceivably could be diverted from one ecosystem to another, but care would have to be taken not to violate the other constraints described here.

In a sustainable agriculture, human health is not jeopardized. This requirement mainly addresses the use of pesticides and fertilizers that may have detrimental effects on humans, especially people that live or work on the farm. The implications of this criterion are both local and regional. Insecticide poisonings or nitrate contamination of ground water supplies often are local effects. Threats to health that occur on a larger scale are fertilizer contamination of water bodies and health risks from pesticide residues on produce.

A sustainable agriculture does not cause extinctions of species. Of the four considerations listed here, this one is more a highly desirable human value than an absolute ecological criterion for a sustainable agriculture. Agriculture may be sustainable in the absence of some indigenous species of a given ecosystem. However, it is already largely accepted that the genes of wild relatives of modern cultivars as well as other undomesticated species will be needed to sustain the viability of our crop species over time (Myers, 1989). Similarly, future pest control options using predatory and parasitic insects also depend on how well biodiversity is maintained in ag-

ricultural and natural ecosystems. For example, Townes (1971) estimates that the biology of only about 3 percent of the parasitic Hymenoptera (the order which includes most effective biocontrol parasites) has been studied. Because our present knowledge of species interactions in natural and agroecosystems is limited, and because our future needs for germ plasm, biological control agents, and yet undiscovered uses of species are unknown, we think it prudent to protect species diversity as a whole.

As with the other parameters, the maintenance of species diversity has very broad implications both on and off the farm. Some examples of these are: the need to design landscapes that provide adequate habitat for the survival of indigenous species in farming regions; the prevention of gene movement from bioengineered crop plants into weedy species that could in turn drive other plant species extinct through competition (Hoffman, 1990); and the contribution of agriculture to the process of global warming through production of methane in rice paddies, release of nitrous oxide from heavily fertilized fields, and release of carbon dioxide resulting from the replacement of tropical forests with permanent pastureland (Ryden and Lund, 1980; Detwiler and Hall, 1988).

Madden (1987) refers to ecologically sound farming practices as "ecologically harmless." We contend that agriculture necessarily perturbs natural ecosystems greatly and is never ecologically harmless. The question is: How can agricultural systems be designed that function within basic ecological constraints? In some places, it may be impossible ever to succeed in farming within the constraints described here, but this is no reason to change the definition of what is ecologically sustainable. In the same way that any ideal provides us with a measure of where we are and where we would like to go, ecological constraints shape the boundaries of long-term sustainability in agriculture.

Sustainability and the social structure of agriculture

Many authors have been interested in how social relations or institutions affect agricultural sustainability. There are two parts to this inquiry, the first being the relationship between ecological sustainability and the social structure of agriculture, and the second being the sustainability of social relations. From the decline of the Roman Empire (Carter and Dale, 1974) to the Dust Bowl of the 1930s in the U.S. (Worster, 1979), people have created agricultural systems that were in conflict with basic ecological limitations of their biomes. One present day example of conflict between social relations and the ecological sustainability of farming practices can be found in many Latin American countries where agribusiness has displaced small landholders from productive bottom lands onto less fertile hillsides. In this case, the accelerated erosion inevitably resulting from cultivation of hillsides places this social structure in direct conflict with ecological sustainability (Williams, 1986). Similarly, Buttel (1990) argues that the social structure of agriculture in the United States "limits the possibilities for redesigning production systems in line with agroecological principles and environmental constraints." To achieve ecological sustainability, society cannot be organized in ways that force farmers to adopt practices that violate ecological constraints.

The second part of the inquiry addressing how social structures relate to agricultural sustainability involves the sustainability of the social relations themselves. Several authors have included measures of social justice or quality of life for farmers or rural communities as necessary components of a sustainable agriculture (Keeney, 1989; Francis and Youngberg, 1990; Hassebrook, 1990). We wholeheartedly agree that these issues urgently need to be addressed by society. However, we assert that sustainability is a measure of a system's potential to endure and is not the proper yardstick with which to measure the desirability of a particular set of social relations. History is replete with examples of dynasties and states that exhibited great longevity in spite of social relations riddled with injustices and inequities. Should these societies be held in high regard just because they were sustained over time? We think not. Issues of rural quality of life and socia justice should be thoroughly considered but not subsumed under the heading o sustainable agriculture.

Having stated this, we think it is important to voice support for the work o those that are involved in understanding how a society has organized or will organize itself to support sustainable land management. Indeed, difficult work is ahead in determining how society can be equitable and just while encouraging ecological sustainability.

Sustainability and profitability

We think that the profitability of an agroecosystem is so tightly linked to the social structure of agriculture and ecological components of sustainability tha it should not be considered a criterion in itself. When considering economic sustainability, it is easy to get caught in a logically circular argument. The logic goes something like this: If a farmer employs an alternative, ecologically sound farming practice, such as a particular crop rotation, and yet cannot turn a profit, then the practice is clearly not sustainable. The rationale of this logic is that the practice could not be carried on indefinitely because it is not economically feasible. This outcome apparently violates the most basic definition of sustainable agriculture, that a given farming system can continue indefinitely. We believe, however, that economic viability may not be a useful criterion for defining sustainable agriculture for three major reasons.

1. The unstable market. Let us suppose that the unprofitable crop rotation mentioned above becomes profitable because a government incentive program is altered, because a change in the price of energy affects the price of nitrogen fertilizers, or because an herbicide is banned. Are we now to be satisfied identifying this crop rotation as sustainable when yesterday it was not? Given the certainty of future economic fluctuations, it is doubtful that many farming practices will ever remain profitable indefinitely.

2. The unsustainable society. Give

the current demographic pattern of densely populated urban areas and vast, sparsely populated farming regions in the United States and elsewhere in the world, few farms could possibly meet energetic and nutrient recycling criteria we consider important for ecological sustainability. In addition to demographics, consumptive demands for unblemished produce, fresh produce out of season, and a diet high in meat stand in the way of a sustainable agriculture. In some cases, these consumptive and demographic patterns prohibit widespread adoption of farming systems that simultaneously are ecologically sustainable and profitable. If an ecologically sustainable farming practice does not turn a profit, then we should look critically at our social structure to determine why, rather than use this economic indicator to judge the practice as unsustainable.

3. The basis of economic sustainability. That economic well-being is ultimately derived from the mineral and biological resources of a society is not a new concept (Odum and Odum, 1981; Riddell, 1981). However, the logic behind this statement has important implications. If one accepts the ecological guidelines of sustainable agriculture set forth above, it is evident that the ecological constraints on agriculture ultimately will interact with the social structure of agriculture to determine what is profitable. Profitability, on the other hand, will never determine what is ecologically sustainable.

If we use both economic and ecological criteria to define sustainability, progress toward ecological sustainability almost certainly will be hindered. We should work toward structuring society in such a way that sustainable agricultural practices are profitable (for example, by modifying commodity programs to end incentives for continuous corn cropping), rather than including profitability within the definition itself.

Conclusion

Over the last decade, farmers, social and natural scientists, and policymakers have made considerable strides in identifying ecological and cultural aspects of modern agriculture that we need to change. Impressive change has already begun. Possibly for lack of a better umbrella term, much of this work has been put under the heading "sustainable agriculture." We contend that such unification is not only unnecessary, but damaging. Many of the issues subsumed under sustainable agriculture could stand alone, and indeed should be recognized as intrinsically desirable social values. Grouping so many diverse and even conflicting objectives obscures the sobering implications of what constitutes an agriculture that can endure indefinitely.

We have held that agricultural sustainability is ultimately delimited by ecological constraints. We contend that a rigorous and unambiguous definition of what comprises an ecologically sustainable agriculture is critical for evaluating the current situation and future direction of society. Finally, we propose that economic profitability not be considered a necessary condition of agricultural sustainability, but rather an indicator of the extent to which a society is operating within critical ecological constraints.

Acknowledgments. We would like to thank John Saponara, Fred Buttel, and the members of the Agricultural Ecology Discussion Group at Cornell for their comments and insights on this manuscript.

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LETTERS TO THE EDITOR INVITED

The AJAA welcomes letters, short or long, commenting on articles in this journal or sharing ideas likely to be of interest to other AJAA readers. Since our space is limited, we do reserve the right not to publish all letters or, at times, to publish only excerpts from them. To take part in this exchange of ideas, write to: Editor, AJAA, 9200 Edmonston Road, Suite 117, Greenbelt, MD 20770.

Farmer First: Farmer Innovation and Agricultural Research. 1989. Edited by Robert Chambers, Arnold Pacey, and Lori Ann Thrupp. Intermediate Technology Publications, London, and The Bootstrap Press, New York, New York. xx + 218 pp. $23.50, paper.

Farmer First is a compilation of papers written by a veritable Who's Who in small-scale agricultural development. The book is directed toward all who work in technology development in the Third World, but it would provide food for thought for professionals working in technology development in more advanced countries as well. This problem-solving approach is presented as complementary to, not a substitute for, the top-down, discipline-driven approach to technology development now common in most of the world.

The book is divided into four parts. The first is a compilation of cases showing how small-scale farmers experiment and innovate on their own. It stresses the importance of indigenous technological knowledge (ITK) for technology generation by scientists and technical workers. Included is a convincing discussion by Dianne Rocheleau and others of the importance of ITK in agroforestry research because of the large number of species available and their long life cycle and the implications these have for designing formal agroforestry experiments.

Part 2 is based on the argument that many professionals assume they know what farmers want and need, but often are wrong. It describes approaches and experiences that illustrate how to help farmers participate in diagnosing problems and choosing research priorities. Roland Bunch argues that this is not a one-time process, but rather a continuing need as biophysical and socioeconomic conditions change. Louk Box makes the important point that farmers in the farmer-first approach are talked *with*, not talked *to*. Throughout this section, it is acknowledged that social scientists play a key role in developing the necessary dialogue with farmers.

Practical ways in which farmers can participate in on-farm research are the subject of Part 3. Again using case studies for illustration, methods are discussed for selecting problems to be studied, treatments (technologies) to be tested, and appropriate evaluation criteria for judging results. To enhance diffusion, most emphasis is given to group rather than individual farmer participation.

Part 4 treats the institutional changes and actions required for technological innovation that is farmer pulled (informal R&D) rather than scientist pushed (formal R&D). It is recognized that appropriate changes not only are difficult to achieve, but once achieved tend to revert to the more formal structure: "For professionals to innovate by working in the farmer-first mode demands vision and leadership on the part of those with power and responsibility... Leaders can act like normal professionals and normal bureaucrats who simplify, standardize and stifle; or they can break out and encourage and support initiative and change."

The editors have attempted to arrange the book to be used as a text. However, to me it seems more useful as a reference and source of ideas. This is reason enough for it to be made widely available to its intended audience--"all concerned with agricultural research, extension and development regardless of discipline, profession or organization"--as well as university and technical school students. -- *Peter Hildebrand, Professor, Department of Food and Resource Economics, University of Florida, Gainesville, FL.*

Sociology of U.S. Agriculture: An Ecological Perspective. 1990. By Don E. Albrecht and Steve H. Murdock. Iowa State University Press, Ames, Iowa. 249 pp. $24.95, hardbound.

Albrecht and Murdock seek to account for the profound changes in agriculture and rural communities in the United States during the 20th Century using human ecology theory. This theory of human social life, derived from general ecological theory, was elaborated systematically in 1950 by Amos Hawley in *Human Ecology: A Theory of Community Structure* (general ecologists should attend closely to Chapter 2 for definitions of concepts with familiar names). It incorporates variables pertaining to the characteristics of human populations, natural environments, technologies, and the way populations are organized to adapt to their conditions. The theory provides a lens for interpreting the wide range of data bearing on agricultural change that Albrecht and Murdock present on each of these four categories of variables (Chapters 4 through 7) and for conjecturing about the future (Chapter 9). Their efforts toward understanding how a complex set of material and social factors interact to shape agriculture are salutary. They supply a wealth of information in the numerous tables and figures in the book. Those interested in explaining change in agriculture must contend with Albrecht and Murdock's work and the theoretical perspective they advance ambitiously.

In reviewing the book, I am in a position analogous to that of an agnostic who takes her children to an upper-middle class church because she thinks Christianity is an important part of the culture and that the children should know about it. She finds the music beautiful and even moving, the sermons both thought provoking and often consistent with her own humanistic views, and the fellowship gratifying; but she is not convinced that a supreme deity

really exists. Therefore she remains an outsider, continually reflecting on alternative explanations and interpretations. Though I find much in the book agreeable, I remain an outsider. My chief criticisms of the book and the approach it promotes are tied closely to its strengths. First, like all theories, human ecology theory enables both selecting salient items from a welter of information and interpreting what is observed, but it also tends to constrain both what is observed and how it is comprehended. The major missing and underemphasized elements are, respectively, human action and the broader political economic context of agriculture. How do those participating in agriculture (defined broadly) understand their social and natural environmental situations and how does this affect how they react to natural and social constraints and creatively make new opportunities? How do the national economy, public policy, and changing international markets affect agriculture? The theory has marked functionalist and rationalist underpinnings in that it presupposes that observed patterns are adaptive and have occurred for reasons surmised by the theorists, bases that many *AJAA* readers will find arguable. Second, the complexity and generality of the model make it difficult to test. Doing so will require ambitious research programs spanning disciplines, time, and geography. Its empirical base in the U.S. in the 20th Century may limit its applicability to other settings if the processes work differently in those settings. Third, the great amount of detailed information in the tables make reading the book tedious at times (especially for skeptics). -- *Gilbert W. Gillespie, Jr., Research Associate, Department of Rural Sociology, Cornell University, Ithaca, NY.*

Implications for Reducing Chronic Disease Risk. 1989. Anon. National Academy Press, National Research Council, 2101 Constitution Avenue, NW, Washington, DC. 749 pp.

This book reports the current state of knowledge in regard to relations of diet to risk and severity of several chronic diseases common among U.S. adults. These diseases often constitute a serious problem for the persons threatened or afflicted by them, and the book seems likely to prove helpful in the interest of some of them. The book's potential helpfulness is derived in large part from the high level of expertise of those who prepared it. A committee of nineteen individuals took major responsibility, but an additional group of eighty experts from diverse disciplines also contributed input.

Some indirect but important effects of the book's message on farmers and farming seem possible. It seems not unreasonable to suggest that the book's recommendations for moderate to major change in the kinds of foods eaten by many people may influence future relative demand for different kinds of foods at the food store and ultimately cause shifts in demand felt at the farmer-producer level.

The diet-related health difficulties considered in the book include, among others, cardiovascular problems, hypertension, stroke, atherosclerosis and health problems linked to it, non-insulin-dependent diabetes, obesity and related problems, cancer, osteoporosis, viral hepatitis and cirrhosis of the liver, kidney malfunction, gall stones, and tooth decay.

The dietary components discussed in respect to their influence on the risk of the just-above-named problems include fats and other lipids, proteins, carbohydrates, dietary fiber, fat-soluble vitamins, water-soluble vitamins, minerals, trace elements, electrolytes containing sodium and potassium, alcohol, coffee and tea, and dietary supplements from the drugstore. Cholesterol and its health effects are discussed at length. Calorie intake and other factors, including human inheritance factors and exercise, are examined thoroughly in relation to weight control. An especially large amount of evidence is reported in respect to effects of saturated fats in increasing heart risk; decreases are recommended for many individuals in consumption of beef, pork, whole milk, and cheese, all high in saturated fat. Increases are recommended for many individuals in intake of green and yellow vegetables and citrus fruits. These themes concur with and reinforce major themes in the Report on Nutrition and Health of the U.S. Surgeon General in 1988 and amplify dietary guidelines for Americans released jointly by the USDA and U.S. Department of Health and Human Services in 1985.

The text of the reviewed book is well organized and written in highly readable style. Main sections of the report are clearly delineated by prominent subheadings. Chapter headings follow the subjects mentioned above, making it easy to locate information in respect to a particular question. An executive summary is provided, also an excellent digest of the authors' dietary recommendations and a helpful index. The print is large and clear, the paper heavy, the cover sturdy, and the price of the book moderate.

The book can be expected to be of interest to several different kinds of readers with different but related needs and concerns. Doctors will apply its recommendations in the treatment of patients with the diet-related health difficulties. Dieticians working in nursing homes and hospitals will consider its message and use it in choosing diets for patients.

Researchers pursuing investigations in the field of human nutrition will appreciate and use the book's thorough documentation in terms of references to recent research. Writers of short popular books on human nutrition and articles on related matters in magazines and newspapers will rely on it as a basic source of authentic information.

Private citizens purchasing food supplies will in some cases be aware of the unexcelled reputation of the National Research Council and be inclined to heed the book's dietary recommendations. Some farmers may find it to their advantage to guide agricultural production on their farms in directions leading to foods that decrease risks of chronic diseases. -- *P. B. Marsh, Consultant, Institute for Alternative Agriculture, Greenbelt, MD.*

Bender Elected President of IAA Board

At the IAA Board's annual March meeting, held this year at the National 4-H Center in Chevy Chase, Maryland, Jim Bender, a commercial scale organic farmer from Weeping Water, Nebraska, was elected President of the IAA. Michael Heller, Manager of the Chesapeake Bay Foundation's Claggett Farm in Maryland, was named Vice President. Dr. Katherine Clancy of Syracuse University and The Honorable Robert O. Blake of Washington, DC, were reelected Treasurer and Secretary, respectively.

The Board heard an interim report from Robert Gray, President of Resource Management Consultants, Inc., Washington, DC, on interviews he is conducting with agricultural leaders. Gray's work is part of IAA's strategic planning process, which is being carried out under a planning grant from The Ford Foundation.

The Institute's 1993 conference will address needed policy reforms, with a special focus on ways to "build bridges" of understanding and dialogue across major U.S. agricultural regions.

IAA Conference Examines Farming-Rural Community Ties

The many critical links between alternative agriculture and rural communities–and their constituencies–were analyzed at the IAA's 9th Annual Conference on March 2-3, entitled "Alternative Farming Systems and Rural Communities--Exploring the Connections." Welcoming the 200 registrants from 36 states and 107 organizations, IAA Executive Director Garth Youngberg said that the adoption of sustainable farming systems "could begin to restore vibrancy to rural areas" hardhit by the increasing dominance of commercial and contract farming in the 1970s and 1980s.

In the opening speech, Dr. Sara Ebenreck of St. Mary's College noted that humans are a "community-creating species," and that "our vision of who we really are, as members of multiple communities, is deepened and made ever more alive when we seek to make the connections between all the communities we belong to." A healthy local community must have a sound economy, positive social indicators, interaction with outside groups, and a "sense of the life of the mind and spirit," she concluded.

North Dakota farmer Dr. Fred Kirschenmann spoke of local sustainable agriculture networks as new rural communities which could invent new answers to the question, "What can farming and rural communities do for each other?" Because "sustainable agriculture dances with nature," he said, it "may reconnect us with nature in a manner that could make the evolution of ecological and social standards for rural communities inevitable."

At the center of the debate about the health of rural communities and American farms is sustainable agriculture, according to Marty Strange of the Center for Rural Affairs. He proposed that "alternative agriculture as a movement is dying--a victim of its own success--but will be reborn." The most important future issue for sustainable agriculture, he said, is not how big can a sustainable farm be, but how small does a farm have to be to be sustainable?

Several other speakers analyzed sustainable agriculture's past and present lessons and what they might mean for the well-being of rural communities. Sustainable agriculture needs committed people and public policies to ensure reasonable profits, according to Mark Ritchie of the Institute for Agriculture and Trade Policy. Also required is active dialogue between farmers, farmers' organizations, researchers, and policymakers in order to develop policies that will address the nation's food, farm, social, and environmental needs, according to Kurt Rohland, a dairy farmer who heads the National Family Farm Coalition. Rudi Buntzel, who works with sustainable agriculture farmers in Germany, offered an international example of organic farmers so successful that the agricultural collectives have shifted to organic farming to compete in the now profitable market of organic produce.

Five work groups that concluded the conference developed strategies to restore or create healthy connections between agriculture and rural communities, with a consensus of participants agreeing that there is a need to mobilize scientists, young people, and other newcomers to the sustainable agriculture movement. All also agreed that survivability is the first requirement for sustainability--and that the people who care about sustainable agriculture and rural communities have much in common, much to share, and much to gain by working together for that survivability.

Dr. Warren Sahs Receives Trailblazer Award

Dr. Warren Sahs, Professor Emeritus at the University of Nebraska and a former IAA President, has received a 1991 "Safe Food Trailblazer" award from the Center for Science in the Public Interest. Dr. Sahs was honored for his outstanding achievement, "leadership, and courage in becoming the first mainstream agricultural scientist to initiate long-term research trials comparing conventional and organic production systems."

Guide for authors

The American Journal of Alternative Agriculture (AJAA) publishes original research on biological, physical, or social science aspects of alternative agriculture. We particularly welcome multi-disciplinary studies, but papers from a specific discipline also are invited. However, since AJAA readership is much broader than for a single-discipline journal, highly specialized terminology should be explained or avoided. The significance of a statement, or the reasoning behind a conclusion, may have to be spelled out more than in a more specialized journal. See Vol. 5, No. 1, pp 2 & 3, for an explanation of the various categories of articles.

Units

Research papers should use the International (SI, or metric) system throughout. Occasional use of common unit equivalents in parentheses is permitted, mainly for relatively exotic SI units.

Title page

The title page should give the following information (all flush left): 1) title of the paper; 2) names of authors; 3) affiliation and office address of authors, and 4) acknowledgements, if any. See examples in this issue of AJAA.

Abstract

The abstract should be 200 to 400 words suitable for readers from a broad range of disciplines. It should avoid highly-specialized terminology that might be appropriate for a single discipline journal. Take particular care that the significance of the work is made clear, even to readers from a different field.

Key words

Provide subject matter key words suitable for use in scientific indexing.

Reference list

When citing material that has been covered in more than one format, such as the typescript of a conference presentation and a journal article, preference should be given to the version that is most readily available, and that is likely to remain so. Generally this means standard publication channels, such as books, journals, and regular government report series. Unpublished or informally-published material should be cited only when no alternative form exists.

References should be listed in alphabetical order by author's name, and by year for a particular author (with letters after the year if needed). If a sole author is also the lead author of papers with multiple authors, use the following order: single author (by year); two authors (alphabetically by second author's name); three or more authors (by year). Repeat the author's name for each reference. Use initials only for first and middle names. Give the names of all authors in the reference; never use "et al."

Use full names of journals, institutions, conferences, etc., except for extremely familiar abbreviations like "Dept." Remember that an abbreviation familiar to you may not be familiar to readers outside your field. If in doubt, write it out.

The reference list uses no quotation marks, italics, boldface, or underlining. Only the names of books and periodicals are in initial capitals. Names of papers, book chapters, pamphlets, and bulletins are not capitalized. Page numbers are written out in full (e.g., 1108-1123, not 1108-23). The volume is given if page numbers begin at 1 for each issue.

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Cite references in the text by last name and year, with chapter or page numbers if the reference is a book or lengthy report. For two authors, give both names. Do not use "et al." unless there are at least three authors.

Footnotes

AJAA does not use bibliographic or substantive footnotes. All bibliographic references should be at the end of the text. Instead of substantive footnotes, include the material in the main text or consider eliminating it.

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The entire manuscript, including abstract and references, should be typed on one side of standard-size paper, double spaced, with margins of at least one inch all around. Starting with the title page, label all pages in the upper righthand corner with the lead author's last name and the page number. Do not use hyphens unless the hyphen is part of the word.

Follow the section headings style used in this AJAA issue. All headings are flush left, with no underlining or italics.

Tables should fit on one page, be numbered consecutively with Arabic numerals, and be on a separate sheet. Leave extra space to separate columns. Every figure and table should be mentioned at least once in the text.

Submission of manuscripts

Submit four high-quality copies to Editor, American Journal of Alternative Agriculture, Suite 117, 9200 Edmonston Road, Greenbelt, MD 20770. The cover letter should state that the manuscript is an original contribution that has not been published elsewhere in substantially the same form; that it is not currently under consideration elsewhere, and that permission has been obtained for any copyrighted material used.

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A growing number of Americans have become concerned about the long-term sustainability of our food production system. Farmers and agricultural scientists are among those raising questions about the growing dependence of modern farming on nonrenewable resources, the depletion of our resource base through soil erosion, and heavy reliance on chemical fertilizers and pesticides. Continued heavy reliance on farm chemicals is questioned because they have become an expensive production input. Their widespread use also raises questions about human and animal health, food quality and safety, environmental quality, and the continued demise of the family farm.

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